NOTICE

All drawings located at the end of the document.

FINAL

PHASE II RFI/RI AQUIFER TEST REPORT

VOLUME I - TEXT

ROCKY FLATS PLANT

903 PAD, MOUND, AND EAST TRENCHES AREAS (OPERABLE UNIT NO.2)

U.S. DEPARTMENT OF ENERGY

ROCKY FLATS PLANT

GOLDEN, COLORADO

ENVIRONMENTAL RESTORATION PROGRAM

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FINAL

PHASE II
RFI/RI AQUIFER TEST REPORT
903 Pad, Mound and East Trenches Areas
Operable Unit 2

Prepared for

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FINAL PHASE II RFI/RI AQUIFER TEST REPORT
903 Pad, Mound and East Trenches Areas
Operable Unit 2

1.0 INTRODUCTION

The Final Phase II RFI/RI Aquifer Test Work Plan, Technical Memorandum 3 (TM3), for Operable Unit 2 (OU2)(EG&G, 1992) provided a plan to evaluate the hydraulic characteristics of selected hydrostratigraphic settings within the surficial material and uppermost bedrock in the vicinity of the 903 Pad, Mound, and East Trenches areas (Figure 1). As set forth in TM3, three multiple-well aquifer tests were proposed as a method of evaluating aquifer parameters. Additionally, two tracer tests were proposed as part of the Aquifer Test Work Plan as originally outlined on pages 5-35 through 5-40 of the OU2 Phase II Work Plan (EG&G, 1991a) which was incorporated in part by the TM3.

These proposed aquifer and tracer tests were implemented between April 28, 1992, and June 26, 1992. This report describes the field procedures, analytical methods, and results of the hydrologic and tracer testing implemented at OU2.

Hydrologic testing was performed in an effort to meet the goals of TM3 and to understand the hydraulic characteristics of the material directly underlying OU2. The goals of these tests were to: 1) develop parameters for rate of movement calculations (hydraulic conductivity, dispersivity, and effective porosity) for both the bedrock and alluvial materials; and, 2) investigate a potential hydraulic connection between the alluvium and the bedrock.

The Rocky Flats Alluvium consists of unconsolidated, poorly sorted sandy gravels to clayey sands and ranges up to 40 feet thick in OU2. These materials unconformably overlay the

Arapahoe Formation claystone and sandstone bedrock. The uppermost Arapahoe sandstone is believed to occur as a paleochannel and as such, is not expected to be present uniformly under the alluvial material in the OU2 area. The extent of the Arapahoe sandstone in the OU2 area depicted in Figure 2 is based on Interpretation No. 2 as presented in the Geologic Characterization Report (EG&G, 1991b). The Rocky Flats and the Arapahoe Formations contain groundwater but have generally been described as having relatively low hydraulic conductivities (EG&G, 1991b and 1991c).

Three constant-rate pumping tests, one slug test, and two radially converging tracer tests were conducted at the three test sites (Figure 2) designated in TM3. The test sites represent three hydrologic settings (Figure 3):

Test Site 1 - unsaturated alluvium over saturated sandstone;

Test Site 2 - saturated alluvium over saturated sandstone; and,

Test Site 3 - saturated alluvium over claystone.

2.0 BACKGROUND TRENDS

Well water levels, barometric pressure readings, and precipitation data for the months preceding aquifer testing were reviewed prior to the implementation of the work plan. Barometric pressure trends were compared to well hydrographs to investigate the effect of pressure changes on water levels. Precipitation data were reviewed with well hydrographs to assess the rate of recharge to the uppermost hydrostratigraphic unit. In addition, barometric pressure and precipitation data for the test interval at each site were reviewed to detect "events" which may have affected the test data.

2.1 WATER-LEVEL TRENDS

Collection of OU2 water-level data for the months prior to pump testing were conducted in order to aid in the selection of test sites and to identify water-level trends. Water levels at six well pairs were monitored beginning January 23, 1992, and continued for two to five months using pressure transducers linked to stand-alone, battery-powered electronic, programmable data loggers (Figure 2). Hydrographs for the twelve wells are presented on Figures 4 through 9. Data were collected hourly at the six sites for varying lengths of time. A data gap exists for the time interval of February 26 through April 13, 1992 due to a data processing error. Alluvial wells 3587 and 11491 (Figures 6 and 9) were dry and all measurements represent water retained in the sumps below the screens. The hydrograph of well 2487 (Figure 4) exhibits a flat line as part of the curve. This flat line is believed to be due to transducer malfunction and represents the length of one file. Generally, water levels rose during March to peak in early April in the OU2 area. This is consistent with Rocky Flats Environmental Database (RFEDS) data for all RFP wells which indicate a historical high for most wells in April 1992 since the time measurements began in 1986.

A water-level elevation of 5921.7 feet in bedrock well 3687 (Site 1), measured just prior to the pumping test on April 29, was a little higher than the last data point recorded on March 30 for the same well (Figure 6). This suggests that there was no decline in head over that period of time. It is noted that this is inconsistent with the bedrock water-level trend apparent on the hydrographs of other bedrock wells which display marked declines in water levels (Figures 4 and 7).

Alluvial wells 11491 and 5691 (Figure 9) were monitored for months prior to testing at Site 2. As noted above, well 11491 was dry for the monitoring period. However, prior to pump testing in June, the water level in well 11491 rose above the sump to an elevation of 5924.82 feet. The hydrograph of well 5691 indicates a malfunction of the transducer. The large offset between data points represents the change in water level during the data gap created by resetting the data logger reference to a hand measurement and is consistent with the rise in water levels seen elsewhere in OU2 wells.

Declining water levels in both the alluvial material and bedrock was an important consideration in the scheduling of tests and the manipulation of test data prior to analysis. Site 3 wells were not monitored in the months prior to pump testing in late May. However, recovery and background trends collected after the drawdown phase of the pumping test support a declining water-level trend consistent with that seen in the hydrographs of other OU2 wells in late April and May (Figures 4 and 7). A thin saturated alluvial thickness, combined with declining water levels, necessitated the use of a peristaltic pump after difficulty was experienced maintaining a constant flow rate with the submersible pump.

2.2 BAROMETRIC PRESSURE

Atmospheric pressure is monitored at the Rocky Flats Plant and was furnished by EG&G in tabular form for the period from January through June 1992. A graphical representation of the barometric pressure over the testing period is presented in Figure 10. The piezometric levels of confined aquifers may be influenced by atmospheric pressure changes, whereas unconfined aquifers usually show no fluctuation due to atmospheric pressure changes. Barometric pressure curves for the drawdown phase of the pumping test at each site are presented in Figures 11, 12, and 13.

Sandstone No. 1 at Site 1 is bounded by lower permeability claystone (Figure 3). However, the piezometric level at the time of observation was beneath the hydraulic confining layer, and, hence, Sandstone No. 1 responded as an unconfined aquifer to variations in barometric pressure. The aquifers at Sites 2 and 3 exist as unconfined aquifers, and, therefore, barometric pressure is not believed to have had an effect during the time of observation.

2.3 PRECIPITATION

Precipitation is monitored at the Rocky Flats Plant and was furnished by EG&G in tabular form for the period from January through June 1992. A graphical presentation of the rainfall is also shown on Figure 10. Rainfall accumulations for the drawdown phase of the pumping test at each site are presented in Figures 11, 12, and 13. Recharge to the tested formation relies on precipitation infiltration within the facility boundary. During the measured periods recharge was low and well water levels throughout OU2 were in decline. There was no measurable precipitation during the testing period at Site 1. During the testing at Sites 2 and 3, rainfall did occur; however, recharge to the aquifer was not evident during the drawdown and recovery phases.

3.0 FIELD PROCEDURE

Three pumping tests, a slug test and two tracer tests were conducted at the three test sites to evaluate aquifer parameters. The pumping tests were constant rate, the tracer tests were radially converging, that is, induced gradient, and the slug test was rising head.

All three test sites are within OU2 and near known trichloroethene(TCE)-laden groundwater plumes. An exclusion zone was configured at each site such that all open wells and storage containers for pumped water were located within the exclusion zone. The zone was marked with yellow caution tape (Figure 14) and Personal Protective Equipment (PPE) consistent with level D was worn by all field personnel.

Power was supplied by a portable generator. A 230-volt alternating current, gasoline-powered generator used at Site 1 had a small fuel tank which required the use of a second generator as change-out for maintenance and refueling of the first so as to minimize the interruptions to power during the length of the test. A diesel generator with a large volume fuel tank was used at the other two sites (Figure 15) which eliminated the need for a second generator and concomitant refueling.

Pumped water was contained in 16,000-gallon capacity frac-tanks (Figure 16); one each at Sites 2 and 3, and two at Site 1. Pumped water was discharged directly into the frac-tanks via the discharge line.

Water levels were recorded continuously by 2-channel data loggers each capable of serving two transducers. The data loggers were housed in locking metal filing cabinets secured to well casings (Figure 17). Transducer cables, which were placed above the land surface, were protected by PVC conduit from both the elements and rodents. Site 1 well transducers were paired to data loggers as follows: 3687 and OB20991, 3587 (no data) and PW20691; OB21091 was not paired. Site 2 well transducers were paired to data loggers as follows: OB20191 and OB20291, OB20491 and OB21191, 5691 and 11491; well 12491 was not paired. Site 3 well transducers were paired to data loggers as follows: OB20591 and PW20691, OB20791 and 1787.

The method of measuring water levels in wells from the top of the inner casing tic mark as set forth in SOP GW.01 (EG&G, 1991d) was not employed. A number of the new wells had not been surveyed, and no tic marks existed. In the interest of consistency and to facilitate rapid measurements of water levels, measurements were made from the top of the protective casing (TOPC). Decontamination was accomplished using a two-towel in-hand system whereby the first towel was wetted in a Liquinox solution and the second towel was wetted in clear distilled water. The measuring tape was run through the towels so that the tape was first wetted with the Liquinox solution and then rinsed in the clear water. This allowed rapid water-level measurements. The method was adequate since groundwater chemistry samples were not being collected. Hand water-level measurements were made with several different brands of electric water-level meters to an accuracy of .01 foot. A rod and placement marker for the rod on the top of the protective casing insured consistent reference points for tape measurements.

Equipment used at each site included an OVM ThermoEnvironmental Instruments Model 500B, calibrated to 100 ppm isobutylene; an Orion pH meter, Model SA250, calibrated with pH 7 and 10 buffer solutions and also capable of measuring temperature; and a Fischer Scientific Specific Conductance Meter, Model 152 (Figure 18), calibrated at 1000 microSiemens per centimeter (µS/cm) at 25°C.

A Grundfos Redi-Flo II submersible pump (Figure 19) was used at Sites 1 and 2. However, for the extremely low flow rates at Site 3, a Geotech peristaltic pump was used. Check valves, located at the pump, were used at all three sites. Discharge tubing from the pump conveyed pumped water through a cut-off valve, through a flow meter, past another cut-off valve, and eventually into the frac-tank. Manual checks in the flow rate were made with a graduated container and a stopwatch at Site 1 and a graduated cylinder and a stopwatch at Sites 2 and 3. Synchronized stopwatches were used by all field personnel.

4.0 ANALYTICAL METHODS

The pumping test data were analyzed by three methods: the Theis (1935) method, the Cooper-Jacob (1946) method, and the Theis Recovery (1935) method. The Cooper-Jacob and Theis Recovery methods of analysis were performed as checks on the Theis curve fitting. Slug test data were analyzed using a method described by Bouwer and Rice (1976). The tracer test data were analyzed with a solution for radially converging flow conditions (Sauty, 1980). A brief summary of the theory and assumptions behind each method is provided in the following sections. For a more complete description, refer to Lohman (1979), Kruseman and De Ridder (1983), or the cited reference. The method of analyzing for directional hydraulic conductivity (Papadopolus, 1965) as discussed in TM3 was not used, as the hydrostratigraphic units at each of the sites were not considered sufficiently homogeneous for the use of this method of analysis.

4.1 PUMPING TEST ANALYSIS

4.1.1 Theis Method for Unconfined Aquifers

The Theis method (1935) was originally intended for the analysis of confined aquifers. However, it can be successfully applied to unconfined aquifers. The Theis solution assumes a constant saturated thickness throughout the duration of the pumping test. Because the saturated thickness decreases for unconfined aquifers subjected to pumping, the drawdown must be adjusted using the method of Jacob (1963).

The time-drawdown relationship for unconfined aquifers often goes through three phases when subjected to pumping (Freeze and Cherry, 1979). During early stages of pumping, unconfined aquifer response may resemble that of a confined aquifer due to the expansion of water and compaction of the aquifer. The time-drawdown curve will resemble the Theis curve. During the second phase, the time-drawdown curve may show a decrease in slope due to gravity drainage. During the third phase, time-drawdown curves will again resemble the Theis curve. Under ideal conditions, the Theis-curve may be matched to the early or late data. However, the storage parameter calculated using early portions of the time-drawdown curve will be in the range of storativity for a confined aquifer. Storage parameters calculated using late portions of the curve will be in the range of specific yield for an unconfined aquifer and should be used to estimate the long-term behavior of the aquifer. The values should be used with caution because of the potential for measurement error and assumptions of the analyzed solution.

The AQTESOLV (Geraghty & Miller, 1989) program was used to apply the method of Theis for unconfined aquifers. This program accepts a maximum of 2000 time-drawdown data pairs. Because the amount of data for the pumping test conducted on all holes greatly exceeded 2000, the number of data pairs was reduced by selectively removing data pairs from the ASCII file while keeping representative points from the total span of the test. AQTESOLV (Geraghty & Miller, 1989) has two options; the user may manually fit the Theis curve to a log-log plot of the data or use an automated estimation routine that uses a non-linear least squares regression to match the Theis curve to all data points. The first option was preferred for the analysis as it facilitates identification of data points that do not conform to the assumptions of the Theis method. Because the aquifer is unconfined, the drawdown was corrected using the method of Jacob (1963). The corrected drawdown, s', is defined as

$$s' = s - \frac{s^2}{2b}$$

where s is the measured drawdown and b is the saturated thickness. This correction was made automatically by AQTESOLV (Geraghty & Miller, 1989).

4.1.2 Cooper - Jacob Method

The Cooper and Jacob (1946) method of analysis was used as a check on the results to the Theis analysis. Cooper and Jacob (1946) showed that for values of $u \leq 0.01$, all but the first two terms in the infinite series expansion of the well function can be omitted. Assuming a value of $u \leq 0.01$ ($1/u = 100$), a linear relationship exists between W(u) and log(u) (or ln(u)), and, hence, the linear relationship between drawdown, s, and log(t) used in the following equation:

$$T = \frac{2.30Q}{4\pi \frac{ds}{d\log(t)}}$$

However, by plotting W(u) versus log(1/u), it can be shown that a linear relationship exists for 1/u values greater than 10.0 ($u < 0.1$). A plot of W(u) versus log(1/u) is presented in Figure 20. Using a 1/u value equal to 10.0 may introduce some error, but the error should be minor. This method was used as a check on the results of the Theis analysis since the data that fit a straight line on a semi-log plot also fit a Theis curve.

Pump test data was analyzed using the method of Cooper and Jacob as follows:

- Following data reduction, the data was imported into a spreadsheet and a semi-log plot of time versus corrected drawdown was created for each well;

- A least squares regression was performed on the linear portion of the plot. The slope, ds'/dlog(t), was substituted into the above equation;

- The value of u was checked to make sure is was ≤ 0.1; and,

- S was calculated using the value of t_0 determined from the regression equation and T from the previous analysis.

4.1.3 Theis Recovery Method

The method of Theis (1935) can also be applied to analyzing recovery data. The solution is derived by superimposing an injection well over a discharging well (or visa versa).

The Theis recovery method was used as a check on the Theis and Cooper-Jacob analyses. Semi-log plots of drawdown, s, versus t/t' were created from the test data. A least squares regression was performed on the linear portion of the plot in a manner identical to the Cooper-Jacob analysis. The slope was substituted into the following equation:

$$T = \frac{2.30Q}{4\pi \frac{ds}{d\log\frac{t}{t'}}}$$

4.2 SLUG TEST ANALYSIS

4.2.1 Bouwer and Rice Method

Slug test data were analyzed using AQTESOLV (Geraghty & Miller, 1989) to apply the method of Bower and Rice (1976). This method is based on the Thiem equation and provides a solution for hydraulic conductivity calculated from the rise of the water level in a well after a volume of water is instantaneously removed. This method can be applied to fully and/or partially penetrating wells in unconfined aquifers. It provides an estimate of the hydraulic conductivity of the aquifer around the screened or open portion of the well.

4.3 TRACER TEST ANALYSIS

4.3.1 Converging Radial Method

A method outlined by Sauty (1980) provides an approximate analytical solution for converging radial-flow tracer tests. Flow conditions may include linear flow with one and two dimensional dispersion, and radial converging and diverging flow. The approximate analytical solution to the transport equation is transposed into dimensionless concentration (C_R), dimensionless time (t_R), and the Peclet number (P). The Peclet number is defined as

$$P=\frac{R}{\alpha_L}$$

where R is the distance from the injection well to the detection well, and α_L is longitudinal dispersivity. The approximate solutions are presented as a series of type curves showing C_R versus t_R for various values of P, and as analytical equations when available. Type curves for converging and diverging flow were generated using a finite difference approximation since no exact analytical solutions exist. Approximate analytical solutions (type curves) are nearly equal to the finite difference approximations for Peclet numbers greater than about 10 for slug injection (Sauty, 1980).

The tracer test data can be analyzed with a curve matching procedure to find values of P and real time, t, corresponding to $t_R = 1$ on the type curves. The equation above is then solved for α_L using the resulting Peclet number. Kinematic porosity is then estimated using the equation below that was derived using Darcy's Law. The value of t_C in the equation below is determined using the relationship $t_R = t/t_C$ where t corresponds to $t_R = 1$ from the curve matching procedure.

$$\Phi_e = \frac{t_c Q}{2\pi R r h}$$

where Φ_e is the kinematic (effective) porosity, Q is the pumping rate, R is the distance from the injection well to the detection well, r = R/2, h is the aquifer thickness, and π is pi.

5.0 SITE 1

5.1 TEST DESIGN

Site 1 was selected to evaluate the hydraulic characteristics of the uppermost Arapahoe Formation sandstone, existing as an unconfined aquifer. At Site 1, the sandstone is separated from the Rocky Flats Alluvium by claystone in existing borehole data (Figure 3). The alluvium was dry as expected, based on historical and background water-level data for the existing alluvial well, 3587 presented in Section 2.1.

Well field spacing, installation, and completion specifications as set forth in TM3 were based upon hydrogeological parameters derived from logs of wells within the test site area, alluvial well 3587, and bedrock well 3687. In addition, preliminary analytical estimates of the expected radius of influence and the effects of wellbore storage, delayed yield, and boundaries were calculated using the hydrogeological characteristics of well 3687.

The installation of three additional wells, two bedrock observation wells (OB20991 and OB21091), and one pumping well (PW20891), was required while existing wells 3687 and 3587 were utilized. Figure 21 illustrates the completion intervals of the wells. Figure 22 illustrates the radial offset of the new and existing observation wells from the pumping well at Site 1.

Drilling began with the observation well closest to the proposed location of the pumping well so that the pumping well could be relocated if necessary. The core of this well, OB20991, was examined by the EG&G hydrogeologist and was found to be consistent with the test scenario. A step drawdown test was not conducted prior to drilling at Site 1 because the design spacing was considered optimal for the existing hydrogeologic conditions. Completion and well design information for all of the wells at Site 1 is supplied in Table 1.

The pumping well, PW20891, was installed in a 10-inch borehole that was drilled to a depth of 64 feet. This well consists of a 2-inch diameter casing/screen and is filter packed from 18.0 to 64.0 feet below ground surface. The formation of completion is Arapahoe Formation Sandstone No. 1. This well was not cored; however, the lithology is assumed to be similar to observation well OB20991, located approximately 5.7 feet to the south, and to observation well 3687 located 10.73 feet to the east.

Observation well 3587, previously installed, had been drilled to a depth of 14.4 feet, and is open from 3.0 to 9.75 feet below surface. The formation of completion is the Rocky Flats Alluvium consisting of gravel, clayey sand, and clay. Silty claystone of the Arapahoe Formation is present below 9.1 feet. Observation wells 3687, OB20991, and OB21091 fully penetrate the uppermost Arapahoe sandstone. The radial distances of observation wells OB20991, 3687, and OB21091 from the pumping well were 5.69, 10.73 and 20.98 feet, respectively (Figure 22). Well construction and lithologic information for all wells is given in Appendix A. Well development information for the new wells is also provided in Appendix A.

The test interval at this site varies from 42 to 48 feet thick and the textures range from clayey sandstone and siltstone to well-sorted sandstones with infrequent sandy claystone and claystone layers. Sandstone occurs at 17 to 21 feet below ground surface and is separated from the alluvium by a 8 to 12 foot thick claystone layer. At the beginning of the pumping test, water levels ranged between 27 and 28 feet below ground surface. The thickness of the saturated interval at the time of the pumping test in the bedrock wells ranged from 28.1 feet in well OB20991 to 33.2 feet in both OB21091 and 3687. The thickness represents the total porous interval (sandstone layers only) below the elevation of the water in the wells. Although an 8 to 12 foot thick claystone layer separates the sandstone from the alluvium, the water level is below the claystone contact indicating unconfined aquifer conditions.

Two geologic cross sections were constructed to illustrate the hydrogeologic setting at the test site. Figures 23 and 24 present the lithologic and hydrologic details at Site 1.

5.2 DATA COLLECTION

The five wells used in the pumping test were configured for electronic data logging of water levels. The Redi-Flo II submersible pump, discharge tubing, safety cable, electric line, transducer cable and drawdown tube were clipped together at five-foot intervals prior to being lowered into the pumping well. The drawdown tube, consisting of a notched polyethylene pipe, allowed clear access through the well for electronic tape readings of the water level. The pump was set at 45 feet below the TOPC and five feet below the transducer.

5.2.1 Step-Drawdown Test

As set forth in SOP, GW.08 (EG&G, 1991d), an evaluation of the expected yield using a preliminary step-drawdown test was performed (Appendix B). Results of this test were used to estimate a pumping rate, the duration of the effects of wellbore storage, and the radius of influence. The maximum drawdown in the pumping well was predicted by extrapolating the rate of drawdown on a semi-log graph through the proposed duration of the test. Results of this test indicated that all observation wells would be within the drawdown cone and that a pumping rate of 1.6 gallons per minute (gpm) would be optimal. A maximum drawdown of 7.65 feet (25%

of the saturated thickness) was not expected to occur during the duration of the pumping test. The duration of the effects of wellbore storage was expected to be insignificant.

5.2.2 Pumping Test

The constant-rate pumping test began at 1730 hours on April 28, 1992. With the aid of synchronized stop watches, the pump and the data loggers were started simultaneously. The pump was shut down at 1723 hours on May 4 concluding an 8633 minute pumping period. Drawdown, recovery data, and antecedent water-level trends were recorded (Appendix C). The test concluded at 1348 hours on May 11, 1992, concluding a 10080 minute duration recovery period.

The pumping test utilized well PW20891 as the pumping well and wells 3687, OB21091, and OB20991 as observation wells. Observation well 3587 was dry. Water-level information for these wells just prior to pumping-test start at 1730 hours on April 28, 1992 is given in Table 1. These levels were measured using electric tapes referenced to TOPC.

The maximum allowable drawdown in the pumping well was estimated to be 7.65 feet. This drawdown is equivalent to 25% of the assumed saturated thickness of the pumping well. The saturated thickness of the pumping well, 30.61 feet, was based on the average saturated thicknesses of wells OB20991 and 3687 and the static water level measured just before the test began (Table 1). The total drawdown in the pumping well at the end of 5 days of pumping was approximately 7.0 feet, less than the maximum allowable drawdown. Maximum drawdowns in the observation wells ranged from 5.7 feet in well OB20991, to 4.3 feet in well 3687 (Figure 25), and to 3.5 feet in well OB21091.

Recovery and post-pumping background water-level data were collected for almost 7 days. A background trend was judged to be insignificant based on the following:

1) After 7000 minutes into recovery, well 3687 recovered to within 0.3 feet of the static water level prior to the start of pumping almost 11 days earlier, representing less than 0.03 feet of background water-level decline per day (Figure 25);

2) There is no clear trend present in the recovery data (Figure 25); and,

3) There is no indication of declining water levels for this well as discussed in Section 2.1.

5.2.2.1 Factors Affecting the Test

The electric generator for the pump required periodic maintenance which necessitated power termination and interruption of pumping. The period of interruption was generally less than 10 seconds. The first maintenance was done 154 minutes into the test; eleven additional generator switch-overs, with short power interruptions, were done and are indicated on the time-drawdown graph for well 3687 (Figure 26).

The flow meter (totalizer) connected to the discharge outflow did not function properly. An auxiliary method was employed using a graduated container and stopwatch. The Grundfos Redi-Flo II was set at 200 Hz and the flow rate adjusted to 1.62 gpm approximately. Figure 31 indicates times throughout the Site 1 pumping test when well 3687 discharge flow rates were measured over the drawdown (pumping) phase. These flow rate measurements (34 total) ranged from 1.54 to 1.64 gpm with an average flow rate of 1.59 gpm. The time interval with the best

Theis curve and straight line fit is between 10 and 1000 minutes. During this period the flow rate was 1.62 gpm. Flow rates measured throughout the aquifer test are provided in Appendix C.

5.2.2.2 Quality Assurance

The results of data analysis methods for constant-rate drawdown aquifer tests are most accurate when discharge rates are constant during pumping and the gradient induced at the pumping well is not affected. Pumping rates varied during the Site 1 pumping test.

The equipment limitations, such as generator maintenance intervals and/or switch-overs as discussed in Section 5.2.2.1, necessitated pauses of about 10 seconds or less in power to the pump in well PW20891. In addition, it was observed that the check valve located at the pump was not functioning properly, thus failing to retain water in the riser tubing. Consequently, during shutoff, the pumping well received a slug of water which in turn caused a brief, local recharge event. Both of these events were of short duration and were considered insignificant with regard to the aquifer analysis.

Tape measurements of the water levels in the well were used to verify transducer data. The electronic data recorded in the pumping well were erratic. This may have been due to the electromagnetic interference with the transducer caused by the pump. Where a jump occurred in the transducer data, the curve was adjusted to reflect the hand-measured water levels. Minor fluctuations were observed in transducer data from the observation wells as well. These were also adjusted to hand measurements. These fluctuations were coincident with the ends of files as a result of the setting of new reference levels; however, some are unexplained shifts in the middle of files. Transducer data and tape measurements for the wells in Site 1 are included in Appendix C.

5.2.3 Water Quality Parameters

Discharge water was periodically checked, using appropriate on-site instruments, to determine pH, specific conductance (SC), and temperature (Appendix C). Headspace gases at the wells were similarly checked for total volatiles. The pH of the discharge water ranged from 6.8 to 7.5 and the SC ranged from 660 to 790 μS/cm at 25°C. Organic vapor measured in parts per million (ppm) did not exceed 0.0 ppm in the breathing zones at any of the wells.

5.2.4 Tracer Test

A radial flow, induced gradient tracer test was conducted at Site 1 to provide estimates of dispersivity and effective porosity. The test was combined with the pumping test to make use of the induced gradient which extended radially from the pumping well.

Potassium bromide (KBr) rather than Rhodamine WT, as specified in the OU2 Work Plan, and SC were used as traceable sources to make use of analytical equipment already available on plant site. A review of the literature indicated that bromide is a conservative tracer and would be suitable for use in OU2 (Davis, 1985).

The tracer test conducted at Site 1 used well OB20991 as the injection well and well PW20891 as the detection well (Figure 22). The OU2 Work Plan incorporated by TM3, calls for five days of pumping prior to the introduction of tracer. This is to assure a constant gradient between the injection well and the detection well, since steady-state conditions are necessary for the analysis of radially converging tracer tests (Sauty, 1980). After 96 hours of pumping, drawdown data from wells OB20991 and PW20891 indicated that the gradient was at steady state, and had been so for 24 hours of pumping. Since steady-state conditions had been achieved, continued pumping to satisfy the 5 day pumping period condition set forth in TM3 would not have enhanced test conditions. Consequently, the tracer test was begun after 4 days of pumping at 1951 hours on May 2, 1992. Data were collected until the pump was shut down at 1723 hours on May 4, a period of 45.5 hours. Water-level data were collected throughout the tracer test to monitor the hydraulic gradient.

5.2.4.1 Introduction of Tracer into the Aquifer

An initial mass of 3.5 pounds of reagent grade KBr was dissolved in one gallon of distilled water. Complete mixing of the solute in the casing was accomplished by using tubing and a funnel. The tubing was lowered into the well until its lower end was approximately two-thirds of the way down the screened interval. The funnel was fitted to the tubing and the KBr solute was poured into the funnel as the tubing was pulled up through the middle third of the screened interval of well OB20991. After all of the solute had been introduced into the well, the tubing was lowered and raised rapidly several times to aid in mixing.

5.2.4.2 Procedure for Collection of Field Data

Prior to the introduction of the tracer, the SC of the pumped water was measured to establish a background reading. A Fischer-Scientific Specific Conductance meter was calibrated using a standard solution as specified by the manufacturer. After introduction of the KBr tracer to the injection well, SC measurements of pumped water (from the detection well) were made every 30 minutes until the readings indicated a rapid rise in the SC. At this point in time, measurements were made every 15 minutes through the peak of conductance. Samples were collected for later laboratory measurement of bromide ion (Br^-) and SC. The field SC peak was detected in well PW20891 at 1930 hours on May 3 (Figure 27). No correlation was found to exist between values of field SC and temperature (Appendix D). Field SC values are given in Appendix D.

5.2.4.3 Procedure for Collection of Laboratory Data

The response of a pH meter, Orion Model SA250, equipped with a bromide-specific ion electrode, was used to measure the bromide concentration, in millivolts (mV), of the samples collected in the field. The results were compared to a calibration curve to determine corresponding bromide concentration. The SC of the samples was also measured using the Fischer Scientific meter. The results and the calibration curve are presented in Appendix D.

The pH meter reference electrode was filled with electrode solution. The bromide electrode was checked for acceptable performance as follows. Two milliliters (ml) of 5 Molar (M) sodium nitrate ($NaNO_3$), also referred to as Ionic Strength Adjustor (ISA), was added to a beaker containing distilled water and the reference and bromide electrodes. One ml of 0.1 M KBr was added to the beaker and the resulting reading was noted. Then 10 ml more of the 0.1 M solution was added and the reading noted. Because the difference between the two readings was between -54 mV and -80 mV per decade, the electrode performance was determined to be acceptable.

Pre-calculated masses of reagent-grade KBr were weighed and placed in 100-ml graduated cylinders. The cylinders were then filled to the 100-ml mark with distilled water to produce 0.01 M, 0.1 M, and 1.0 M solutions of Br^-. Two ml of the ISA was added to the 100 ml of 0.01 M KBr solution and the pH meter reading was noted. This procedure was repeated with the 0.1 M and 1 M KBr solutions and then twice more with each of the three concentrations to provide three meter readings for each known concentration. The three readings were averaged for each concentration. A calibration curve (Appendix D) was created by converting each molar concentration to milligrams per liter (mg/L) and then calculating the equation of the line resulting from plotting the base-ten log of the concentration against the pH meter reading (in mV).

Each sample was measured and placed in a 100-ml graduated cylinder and 2 ml of the ISA were added just prior to inserting the reference and bromide electrodes into the sample bottle.

The resulting mV value was used in the calibration equation to convert the reading to bromide in mg/L. The results are presented in graphical form (Figure 27) illustrating laboratory bromide concentration and field SC over elapsed time (Appendix D). The arrival time of the laboratory bromide concentration peak is consistent with that of the field SC arrival time.

5.3 ANALYSIS OF PUMPING TEST DATA

5.3.1 Considerations

Wellbore storage effects for pumping well, PW20891, were evaluated using the Schafer method (1978). The time, t_c, at which wellbore storage effects are negligible can be calculated as follows:

$$t_c = \frac{375(r_c^2 - r_p^2)}{T}$$

where t_c is time (in days), r_c is radius of the well casing (in feet), r_p is the radius of the pump column (in feet), and T is the transmissivity (in gallons per day per foot (gpd/ft)). The well casing diameter is 2 inches, and, instead of the pump column, the well casing accommodates transducer cable, pump safety cable, pump electric line, and discharge tubing. Therefore, using the value of r_p in the calculation of wellbore storage takes into account the radii of all of the lines and cables in the well.

Using $r_c = 0.083$ feet

$r_p = 0.064$ feet

$T = 325.2$ gpd/ft (from Table 2)

$t_c = 0.003$ days (4.6 minutes).

Wellbore storage effects are negligible after about 10 minutes of pumping. Therefore, data from the first 10 minutes of pumping were not in the analysis.

Delayed yield in the observation wells of the Site No. 1 well field was estimated using the method of Walton, (1962), valid for wells between 0.7 feet and 20 feet from the pumping well:

$$t_d = (5.4 \times 10^4 m S_y)/K$$

where t_d = time in minutes beyond which delayed yield impacts are negligible

m = aquifer thickness in feet, 30.61 feet

S_y = specific yield, 0.1

K = hydraulic conductivity in gpd/ft^2, 8.83 gpd/ft^2 (Table 2)

The impacts of delayed yield would be negligible after 13 days of pumping. Pumping at Site 1 lasted for only 6 days; delayed yield is not apparent in the hydrograph of well PW20891 (Figures

28 and 29). Consequently, drawdown appears to be following the first Theis segment of the curve for water-table aquifers.

Examination of the drawdown curves for well 3687 (Figures 26, 30, and 31) and well PW20891 (Figures 28 and 29) reveals no evidence of boundary effects. No recharge occurred during the drawdown and recovery phases of the test according to precipitation data provided by RFEDS (Figure 11).

The background water-level trend was discussed previously and the recovery and background water-level trend curve for well 3687 (Figure 25) does not display a decline in head. Therefore, the data were analyzed without a background correction.

5.3.2 Analytical Results

The well parameters used to analyze the test data are provided in Table 2. The pumping rate used for analysis of the wells at Site 1 is 1.62 gpm, which is based on the average pumping rate for the interval with the best Theis-curve and Jacob's-line fits. Values of drawdown used in the Theis and Cooper-Jacob analyses were corrected to s'. Two values of saturated thicknesses used for calculations are given in Table 2 and represent the length of saturated filter pack and the total saturated permeable units. This provides a range of hydraulic conductivities, with the filter pack thickness representing the least conservative (or lower) estimates.

The results of the three methods of analysis are compiled in Table 2. Figures 28 through 38 present the graphical results of the three analytical methods, the Cooper-Jacob straight line analysis, the Theis analysis, and the Theis recovery analysis. The results of all three methods are very similar, with less than an order of magnitude difference occurring between methods and between wells. The hydraulic conductivities are consistent with those expected for well-sorted fine-grained sandstones. Theis Recovery analysis was not performed for well PW20891, since the recovery curve was impacted by the non-functioning check valve.

Storativity values are also provided in Table 2. The values are in the range of confined aquifer storativities. This is consistent with the delayed yield calculations which would put the Theis curve match as at early time.

5.4 ANALYSIS OF TRACER TEST DATA

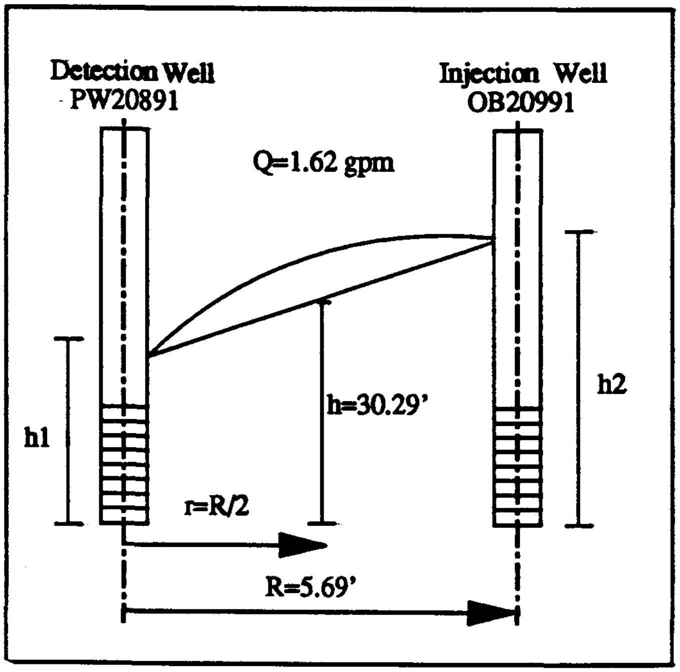
Tracer test data collected at Site 1 were analyzed using the method outlined by Sauty (1980) for the approximate analytical solution of nonreactive transport of solute material from slug injection.

Type curves were generated for dimensionless time equivalent to five days for Peclet numbers 1, 3, 16, 30, 100, 300, and 1000 (Figure 39). Laboratory and field data were converted to dimensionless concentrations and plotted versus real time (t) on the same scale as the type curves (Figures 40 and 41). The experimental data were visually matched to the type curves by overlaying the two plots and moving them until a best fit was achieved. The corresponding Peclet number was determined by interpolating between the two best fitting type curves. The real time, t, corresponding to $t_R = 1$ on the type curves was recorded as 1.15 days for both the field SC and the Br^- data. The curves were matched at P = 30. This value was then used to solve for longitudinal dispersivity and effective porosity using the following equations:

$$\alpha_L = \frac{R}{P}$$

Parameters used for the Site 1 calculations are given in the schematic below.

$$\Phi_e = \frac{t_c Q}{2\pi R r h}$$



The value of t_c is determined using the relationship $t_c = t/t_R$ where t corresponds to $t_R = 1$ from the curve matching procedure.

The results of the analysis provide a longitudinal dispersivity of 0.19 ft. and a kinematic (effective) porosity of 12%. The value of porosity is a realistic estimate for a well-sorted sandstone. The dispersivity, though seemingly small, is a scale related parameter. The distance over which the tracer traveled was 5.69 feet. The dispersivity is consistent with the limited scale of the test. A test conducted over a longer distance is expected to yield a larger value of longitudinal dispersivity. This value should be used in accordance with the scale it represents.

6.0 SITE 2

6.1 TEST DESIGN

Site 2 was designed to test saturated alluvium and bedrock as a single hydrostratigraphic unit where they are in direct hydraulic connection (alluvium overlying sandstone) as is illustrated in Figure 3. The design for Site 2, such as well field spacing and installation and completion specifications as set forth in TM3, were based upon hydrogeological parameters derived from logs of alluvial wells 11491 and 5691, bedrock well 12491, and borehole 11391 within the area of the test site. In addition, preliminary analytical estimates of the expected radius of influence and the effects of wellbore storage, delayed yield, and boundaries were calculated using the hydrogeological characteristics of those wells.

Figure 42 illustrates the radial offset of the new and existing observation wells from the pumping well. Site 2 required the installation of five additional wells: two alluvial observation wells (OB20291 and OB20491); two bedrock observation wells (OB20191 and OB21191); and one pumping well (PW20091). Two existing alluvial wells (11491 and 5691) and one bedrock well (12491) were also utilized as observation wells. Figure 21 diagrammatically illustrates the completion intervals of the observation and pumping wells.

Drilling began with the bedrock observation well closest to the pumping well. TM3 states that step-drawdown testing would be conducted in order to determine the location of well sites. However, upon examination of the core for well OB20391 by the EG&G hydrogeologist, it was determined that the site required close spacing of observation wells due to the clayey nature of the bedrock sandstone. Since the spacing was already as close as was practicable, step drawdown tests were not conducted. Completion and well design information for all wells is supplied in Table 3.

In an attempt to develop the initial pumping well, PW20091, it was observed that the well was partially obstructed in the screened interval. The well could not be developed and was not salvageable as a pumping well. Consequently, the site was re-evaluated with respect to the original test design to assess the practicability of attempting to install a new pumping well. This approach was abandoned based on three concerns. First, due to the close spacing of the observation wells, installation of a new pumping well without intercepting or disturbing other boreholes and while remaining centrally located, was judged to be a difficult task. Secondly, examination of core logs of the newly installed wells indicated that sandstone was separated from the alluvium by several feet of claystone in the observation wells and in the pumping well. This separation of the alluvium and sandstone deviated from the original test scenario which was based on the logs of 12491 and 11391. According to these logs, the alluvium (layer 1) and the sandstone (layer 2) are in direct hydraulic connection. Finally, even if layers 1 and 2 are in hydraulic connection, the descriptions of the sandstones on the logs of the new wells indicate that the sandstones are clayey and of low hydraulic conductivities. This was considered a problem since the purpose of this test was to treat the units as two permeable layers within a single hydrostratigraphic unit. This would require a fully penetrating pumping well with some observation wells open to layer 1 and others open to layer 2, thereby allowing the evaluation of the transmissivities of each unit. However, with most of the flow expected to come from layer 1 and very little from the clayey sandstones of layer 2, the scenario was given little chance of success.

In order to design an alternate plan, step tests were conducted in both units, one in alluvial well OB20291 and one in a bedrock well OB20191. Responses were observed in all of the observation wells during both tests. Analysis of the alluvial step test provided an estimate of hydraulic conductivity in the range of 10^{-3} cm/sec (Appendix B).

An analysis of the bedrock step test indicated a hydraulic conductivity in the range of 4×10^{-5} to 9×10^{-5} cm/sec (Appendix B). Low pumping rates, on the order of 0.05 to 0.075 gpm, were required to maintain reasonable rates of drawdown in the bedrock. At these flow rates the operation of the submersible pump would fluctuate, gradually decaying the flow rate and eventually ceasing to operate. At rates of 0.12 gpm and greater, the pump could maintain a somewhat constant flow rate, but the rate of drawdown was unacceptably high.

The results of the step tests provided several important pieces of information: 1) the alluvium and the bedrock appeared to be hydraulically interconnected, since pumping in one affected the other; 2) the bedrock material, a clayey sandstone, was judged to have a low hydraulic conductance and, in relation to the alluvial material, is capable of transmitting an inconsequential amount of water; 3) the alluvial wells could be considered to be fully penetrating since the lower unit would not contribute a substantial amount to the overall transmissivity; and 4) the pump would probably not provide a satisfactory constant rate of pumping at a rate below 0.12 gpm. Based on this information, the alluvial well, OB20291, was designated the pumping well for an alluvial pumping test. The remaining six wells were observed for responses. In addition, bedrock well OB20191 was slug-tested with the remaining six wells used for observation of responses.

The designated pumping well, OB20291, had been drilled to a depth of 35.6 feet and is open to the Rocky Flats Alluvium from 16.0 to 33.3 feet. It was completed with a two-inch diameter casing inside a 10-inch borehole. Alluvial wells 11491, 5691, and OB20491 served as alluvial observation wells. All are open to the Rocky Flats Alluvium, with well 11491 not fully penetrating. The remaining observation wells, 12491, OB20191, and OB21191, are open to the

Arapahoe sandstone. Wells OB20191 and 12491 fully penetrate the bedrock sandstone. Well OB21191 is open to the bottom 2.5 feet of the alluvium and all of the bedrock sandstone. (This well was drilled based on lithologic information provided by adjacent wells and was not cored.) Well logs and completion information are included in Appendix A. Well development information for the new wells is also included in Appendix A.

Pre-test static water levels were similar in both the bedrock and alluvial wells, indicating that the alluvium and bedrock sandstone exist as a single hydrostratigraphic unit in the area of Site 2. Based on core logs, the lateral extent of claystone present between the alluvium and the bedrock may be limited and may allow a direct interconnection as illustrated in Figure 43.

The lithology of the saturated alluvium is fairly uniform throughout the test site, consisting predominantly of clayey sand, some clay, clayey gravel, and minor well-graded gravel. Saturated thickness, as determined by the distance between the water table to the top of bedrock at the time of pumping, ranged from 8.82 feet in well OB20491 to 12.89 feet in well 5691. The saturated thickness in the pumping well, OB20291, was 10.84 feet.

The lithology of the bedrock is also fairly uniform at the site consisting predominantly of clayey sandstone, sandy claystone, and minor sandstone. Overall the sandstone interval thicknesses ranged from 35 feet in well 12491 to 23.9 feet in well OB20191. Total permeable thickness (sandstone layers only) ranges from 31.5 feet in well 12491 to 12.8 feet in well OB20191.

Two geologic cross sections were constructed to illustrate the hydrogeologic setting that was tested. Figures 44 and 45 present the lithologic and hydrologic details at Site 2.

6.2 DATA COLLECTION

Seven wells (Figure 42) monitored during the pumping and slug tests were configured for electronic data logging of water levels. A ground wire was attached to the transducer in the pumping well and run to the data logger to avoid electromagnetic interference caused by the pump. The submersible pump, discharge tubing, safety cable, electric line, transducer cable, and the ground wire were strapped together at five foot intervals prior to being lowered into the pumping well. The pump was set at about 33.5 feet below the TOPC (31.28 feet below ground surface), five feet below the transducer. The generator had a large volume fuel tank which allowed the pump to be run continuously without a shut-down for generator maintenance.

6.2.1 Step-drawdown Test

As set forth in SOP, GW.08 (EG&G, 1991d), the expected yield was evaluated using preliminary step-drawdown tests, one in alluvial well OB20291 and one in bedrock well OB20191. Analysis of the results of the step test in bedrock well OB20191 led to the use of a slug test to characterize the bedrock. The step tests are discussed in Section 6.1. Results of the step test in alluvial well OB20291 (Appendix B) were used to estimate a pumping rate, the duration of the effects of wellbore storage, and the radius of influence. Hydraulic conductivity was also estimated so that the maximum drawdown in the pumping well could be predicted. Results of this test indicated that all alluvial observation wells would be within the drawdown cone and, that at a pumping rate of 0.35 gpm, wellbore storage would be insignificant. A maximum drawdown of 2.7 feet (25% of the saturated thickness) was not expected to occur for the duration of the pumping test.

6.2.2 Pumping Test

The constant-rate alluvial pumping test began at 0917 hours on June 23, 1992. With the aid of synchronized stop watches, the pump and the data loggers were started simultaneously. The test ran for 1967 minutes at a pumping rate of 0.35 gpm and then for approximately an additional 90 minutes at 0.13 gpm before the generator failed. Recovery data and antecedent water-level trends were recorded at 30-minute intervals for 750 minutes. The test concluded at 0805 hours on June 25, 1992. Field data collected during the test are provided in Appendix C.

The pumping test utilized alluvial well OB20291 as the pumping well and alluvial observation wells OB20491, 5691, and 11491. Also monitored were bedrock wells OB20191, OB21191 and well 12491. Water-level information for these wells just prior to pumping-test start is given in Table 3. Depth to water in the well field was between 21.96 (OB21191) and 22.77 (OB20491) feet below ground surface. These water levels were measured using electric tapes referenced to TOPC.

The maximum allowable drawdown in the pumping well was estimated to be 2.7 feet. This is equivalent to 25% of 10.87 feet, the saturated thickness of the pumping well, OB20291. The saturated thickness was based on the difference between the static water-level elevation and the elevation of bedrock (Table 3).

After the pumping test had been running for almost 24 hours, it was noted that the rate of drawdown in the pumping well increased sharply at about 1000 minutes causing the maximum allowable drawdown to be met. This indicated that effects similar to that of a low permeability zone had been felt (Figure 46). At the request of the EG&G hydrogeologist, pumping at 0.35 gpm was continued in an effort to define the possible low permeability boundary. At about 1850 minutes after pumping had started, the water level drew down below the transducer in the pumping well. A new pumping rate of 0.13 gpm was used to reduce the radius of the drawdown cone to avoid interference by the possible low permeability zone. The pumping rate was adjusted at 1804 hours, June 24. The generator failed approximately 90 minutes following the reduction of pumping rate. The pumping test, including recovery time, ran for 1 day, 22 hours, and 48 minutes (2808 minutes).

The total drawdown in the pumping well during pumping fell to 4.58 feet, well beyond the maximum allowable. Maximum drawdowns in the alluvial observation wells ranged from 0.84 feet in well 5691, to 0.52 feet in well 11491, and to 0.54 feet in well OB20491. Drawdowns occurred in all of the bedrock wells, including 0.45 feet in well OB21191, 0.33 feet in well OB20191 and 0.23 feet in well 12491, clearly indicating a strong hydraulic interconnection of alluvial and bedrock materials.

The recovery data recorded for wells OB20491 and OB21191 are presented in Figure 47. Two observations are notable: 1) the bedrock and alluvial wells have similar background trends, and 2) approximately 0.3 feet of drawdown had not recovered. These observations are apparent on the hydrographs for the drawdown and recovery phases of all of the wells, with the exception of the pumping well, which recovered completely.

6.2.2.1 *Factors Affecting the Test*

As mentioned above, due to generator failure the pump was shut down, and, as a result, the wells recovered. The generator could not be re-started without installation of a new fuel pump. Even though the test did not run as long as was desired, the drawdown data were found to be analyzable.

Since the flow meter connected to the discharge outflow did not function properly, an auxiliary method of using a graduated cylinder and stopwatch was used. The Grundfos Redi-Flo II was set at 170 Hz and the flow rate adjusted to approximately 0.35 gpm. The flow rate remained fairly constant, with a gradual decrease in rate from 0.35 to 0.32 gpm in the first 24 hours of pumping. Over the next 10 hours it decreased another 0.016 gpm to 0.31. The time interval selected as most appropriate for aquifer analysis was the first 1,000 minutes. During the first 1,000 minutes the flow rate averaged 0.34 gpm. Additionally, for the first six hours of pumping the flow rate was known to have remained constant at 0.35 gpm. Pumping rates measured throughout the aquifer test are provided in Appendix C.

6.2.2.2 Quality Assurance

The data used for analysis of constant-rate aquifer tests do not require adjustment if discharge rates are constant during pumping and no other stresses occurred during the test period. Neither of these effects are considered to have occurred during the Site 2 pumping test. The pumping rate can be considered to have remained constant at 0.35 gpm and the background water-level trend appears constant. The hydrographs for drawdown and recovery phases of wells OB20491 and OB21191 (Figure 47) indicate that the water level remained fairly constant during the 12 hours of recovery data. However, there is a net loss of 0.3 feet during the test. This net loss is not compatible with background data acquired during the slug test conducted in well OB20191, which indicated steady conditions. It is possible that delayed yield from storage may have inhibited recovery of the observation wells and that extended recovery measurements would have shown complete recovery. If the principle of delayed yield is applied to the development of a theoretical recovery curve for a water-table aquifer, there will be a flat interval in the curve when both the positive and negative drawdown are on the flat section of the water table drawdown curve. Drawdown data were not adjusted prior to analysis.

Although recovery data was recorded after the generator failed, the data loggers were not recording data logarithmically. The time steps for measurement of data points were too coarse to allow a characterization of the curve, and therefore the data could not be analyzed for hydraulic parameters. Additionally, the pumping rate had been adjusted prior to generator failure, which would have compromised the accuracy of a recovery analysis.

Manual measurements of the water levels in the well were used to verify transducer data. At 1850 minutes into the pumping test the water level declined below the transducer in the pumping well. Although this portion of the curve was not used for analysis, the total drawdown in the well was verified with manual measurements. Additionally, transducer data occasionally fluctuates and where a fluctuation occurred in the transducer data, the curve was adjusted to reflect the hand-measured water levels. These minor fluctuations were observed in transducer data from most of the observation wells. Transducer data and manual measurements for the wells in Site 2 are included in Appendix C.

6.2.3 Slug Test

A slug test was conducted in bedrock well OB20191 on June 19, 1992. The slug test was a rising head type test achieved by rapid removal of water by pumping.

The site configuration was similar to that used for the pumping test, except the submersible pump was placed in well OB20191. In this well the top of the bedrock is 35.46 feet below the TOPC and the bentonite seal is 33.26 feet to 36.46 feet. By placing the pump so that water would not be evacuated below the top of the bedrock, preferably within or just above the bentonite seal, drainage from the filter pack could not occur. This was accomplished by placing the pump about 33 feet below the TOPC. The transducer was hung 5 feet below the pump and fitted with a ground wire. With the aid of synchronized stop watches, the pump and the data loggers were started simultaneously. The pump was pre-set at a high rate of flow so that evacuation of the well bore storage would occur within less than a minute. The pump was started at 1330 hours and turned off as soon as the pump stopped discharging water. A volume of 6.4 quarts of water was pumped in 25 seconds.

A 7.4-foot column of water was rapidly pumped from well OB20191 (Figure 48). The response in both bedrock observation wells, well 12491 (Figure 48) and OB21191 (not shown), were small but clear. The most distant alluvial wells, 5691, 11491 and OB20491, did not respond to the removal of the slug of water. The data for alluvial well OB20291 (Figure 49), located only 9.1 feet from the slug tested well, indicate a response but display little recovery (Appendix C) within the recorded time interval. This response in the alluvium indicates that the bedrock at Site 2 behaves as the second layer of a single two-layer unconfined hydrostratigraphic unit of which the alluvium exists as the upper layer.

6.2.3.1 Quality Assurance

Prior to initiation of the test, the data loggers and transducers were tested to assure accuracy. In addition, manual measurements of the water levels in the pumped well were used to verify transducer data.

6.2.4 Water Quality Parameters

Discharge water was periodically checked, using appropriate on-site instruments, to determine pH, SC, and temperature (Appendix C). Headspace gases at the wells were similarly checked for total volatiles. The pH of the discharge water ranged from 7.7 to 8.0. The SC was measured using the Fischer Scientific Specific Conductance meter calibrated at 1,000 μS/cm at 25°C. The SC of the discharge water ranged from 570 to 720 μS/cm at 25°C. Organic vapor in the breathing zone did not exceed 0.0 ppm at any of the wells.

6.3 ANALYSIS OF PUMPING TEST DATA

6.3.1 Considerations

Wellbore storage was calculated with the Schafer method (Section 5.3.1) used for Site 1. Using a transmissivity of 187 gpd/ft, the time after which the effects of delayed yield are negligible, t_c, is 0.006 days, or 8 minutes. Because the first 16 minutes of data comprise a small part of the analyzed data and the points from about one minute fit the Theis curve well, effects from wellbore storage were considered insignificant.

The background water-level trend was discussed previously in Section 6.2.2.2. There is no clear trend in background data indicating a constant rate of drawdown (Figure 47), merely a recovery that is not 100% of the drawdown. In addition, background data collected after slug testing of well OB20191 (Figure 48) does not suggest a trend of decline immediately preceding the pumping test. Failure to recover completely to pre-test levels may indicate the alluvial aquifer is limited in extent.

The pumping well is fully penetrating and the observation wells are completed either wholly in the alluvium or wholly in the bedrock sandstone as designed, with the exception of wells OB21191 and 11491. Well 11491 does not fully penetrate the alluvial material. However, it is the most distant observation well and its partial penetration is not believed to significantly affect test results. Well OB21191 was installed as a bedrock well. However, completion data reveals that the filter pack extends over two feet into the alluvium. This well was not logged, but based on the logs of wells 12491 and 11391 (Figures 44 and 45) the alluvium may rest directly on the sandstone bedrock. Consequently, the aquifers must be hydraulically interconnected; the degree of interconnectedness is the issue of concern at this test site. It is clear that direct interconnection exists in the northwestern part of this site. In addition, based on the response of bedrock well OB21191 (Figure 47) to the pumping of alluvial well OB20291 and the response of alluvial well OB20291 to slug testing of bedrock well OB20191, an interconnection exists in the rest of the site as well.

Precipitation occurred during and after the test (Figure 12). Recharge to the system is not evident during the drawdown phase and the lack of usable recovery data makes adjustment of the recovery data unnecessary.

Delayed yield in the observation wells of the Site 2 well field was estimated using the method of Walton (1962), described in Section 5.3.1. Using an average saturated thickness of 10.8 feet, an assumed hydraulic conductivity of 17.3 gpd/ft^2 (8.14×10^{-4}cm/s), and an assumed specific yield of 0.1, the time for the effects of delayed yield for wells between 0.7 and 20 feet from the pumping well is 2.3 days. The pumping test lasted less than 1.5 days. Typical delayed yield curves are not apparent in the log-log plots of the time-drawdown data for observation wells OB20491, 5691 and 11491 (Figures 50 through 52). An attempt to fit the log-log plot of the time-drawdown data for well OB20291 (Figure 53), the pumping well, to a delayed yield curve was unsuccessful.

The log-log plots of the drawdown data for the pumping and observation wells show departures from the Theis curves. These departures are consistent with decreases in transmissivity at some distance from the pumping well. If this condition is treated as an imaginary impermeable boundary, the position of the boundary may be estimated using a method outlined by Ferris et al., (1962):

$$r_i = r_r(t_i/t_r)^{1/2}$$

where r_i = radius to the image well from the observation well,

r_r = radius to the pumping well from the observation well,

t_r = time at any point on the curve after the boundary effects are apparent, where the drawdown s_i represents the interval of departure of the curve from the Theis type curve, and

t_i = time on the curve where the drawdown (s_r) on the type curve is equivalent to s_i.

The log-log plots of time-drawdown data of wells 5691, 11491, and OB20491 (Figures 50 through 52) were used to find the location of the boundary. A plot of the circles generated by the calculated radii are shown in Figure 54. The location of the image well that would cause the observed departures is about 65 feet north of the pumping well. This location is consistent with a significant reduction in transmissivity less that 33 feet north of the pumping well. Values used to find this boundary are:

Well	t_i(mts)	t_r	r_i(ft)	r_r
5691	1900	50	51.2	8.3
11491	1900	105	101.7	23.9
20491	2000	105	51.5	11.77

In order to confirm the presence of declining transmissivity to the north of the pumping well, another pumping test would indicate whether the departure from the Theis curve is repeatable or additional drilling in the area of the boundary may define a zone of reduced transmissivity.

6.3.2 Analytical Results

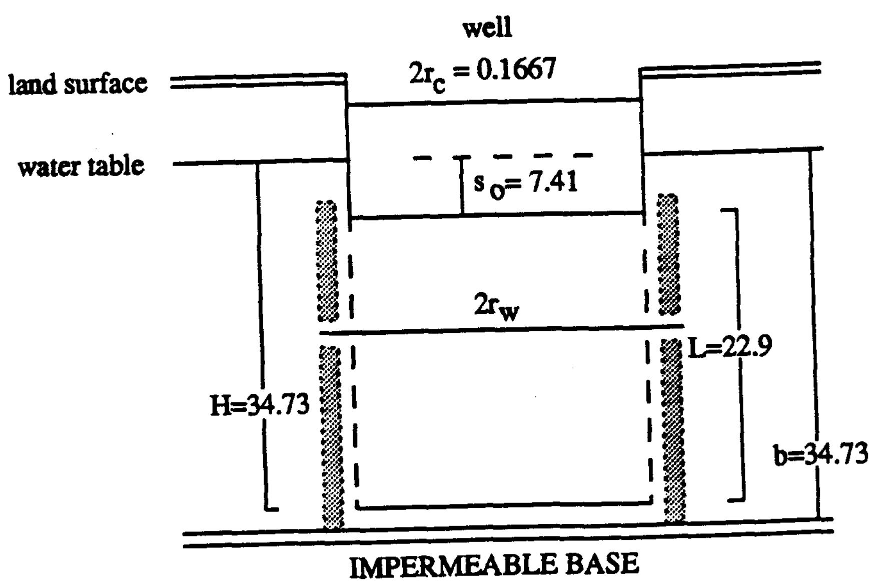
The well parameters used to analyze the test data for each well are provided in Table 4. The pumping rate used for analysis is 0.35 gpm, which is based on the average pumping rate for the interval which was analyzed. This interval is the first 1000 minutes of pumping, before the boundary effect becomes apparent. The saturated thicknesses used for calculations are given in Table 4 and represent the interval between the static water level (pre-test) and the base of the filter pack.

The results of the two methods of analysis are compiled in Table 4. The results are very similar for the three observation wells, with less than an order of magnitude difference occurring between the methods for each well and between wells for each method. Values on the order of 10^{-3} cm/s were found using both the Cooper-Jacob straight line method (Figures 55 through 57) and the Theis method (Figures 50 through 52). The hydraulic conductivity of the pumping well, OB20291, was evaluated using both the Cooper-Jacob (Figure 58) and Theis method (Figure 53) as an order of magnitude lower than the other wells. The Theis analyses of the observation wells are believed to be Type A curves. These are early time curves consistent with the confined response of the aquifer. The values of storativity support this observation, with values in the confined aquifer range. The Theis analysis of the pumping well supports a late time or Type Y curve, with a storage coefficient in the unconfined range, indicating that delayed yield had occurred within the very early part of the curve. The Theis Recovery method of analysis was not used for any of the wells since the recovery data was not appropriate for analysis. The boundary effects are consistent with a reduction in permeability or available saturated thickness.

In summary, the pumping test at Site 2 indicates inhomogeneous material with a transmissivity of about 4.07×10^{-2} ft^2/min within a radius of about 30 feet of the pumping well.

6.3.3 Slug Test Results

The analysis of the slug test conducted in bedrock well OB20191 (Figure 59) provides an estimate of hydraulic conductivity of 9.605×10^{-6} ft/min (4.88×10^{-6} cm/s) for sandstones at Site 2. The parameters used for the calculation are as follows:



where r_c = radius of the well casing,

r_w = effective radius of the well,

s_o = change in water level in the well as a result of the removal of a slug of water,

L = length of the filter pack,

b = saturated thickness, and

H = interval from the water table to top of the impermeable base.

The alluvium and bedrock may exist as separate layers of a single hydrostratigraphic unit at Site 2. A response in alluvial well OB20291 to the slug test suggests a hydraulic connection. However, since well OB20191 is open only to the bedrock, and responses to the slug test were observed in the other bedrock wells, it is believed that the hydraulic conductivity evaluated from the data is representative primarily of the bedrock sandstone.

The analyzed value of hydraulic conductivity is an order of magnitude lower than that analyzed from the step-drawdown test recovery data, but it is reasonable, given the variation in abundance of clay in the sandstones and the small radius of investigation of the slug test.

7.0 SITE 3

7.1 TEST DESIGN

Site 3 was designed to evaluate hydraulic characteristics of the Rocky Flats Alluvium as an unconfined aquifer where it is not underlain by Arapahoe sandstone, but by Arapahoe claystone, as illustrated in Figure 3. The Arapahoe claystone was also monitored to detect a response during pumping of the alluvium in order to evaluate the degree of interconnectedness with the alluvium.

Well field spacing and installation and completion specifications as set forth in TM3 were based upon hydrogeological parameters derived from the log of a well situated within the test site area, alluvial well 1787. In addition, preliminary analytical estimates of the expected radius of influence and the effects of wellbore storage, delayed yield, and boundaries were calculated using the hydrogeological characteristics of this well.

Site 3 design utilized one existing observation well, 1787, and required the installation of three additional wells, two observation wells, one open to the alluvium (OB20591) and one open to the claystone (OB20791), and one pumping well (PW20691). Figure 21 illustrates the completion intervals of the observation and pumping wells and Figure 60 illustrates the radial offset of the new and existing observation wells from the pumping well.

Drilling began with the observation well closest to the proposed location of the pumping well. The core was examined by the EG&G hydrogeologist to evaluate whether the site was consistent with the test scenario. A step-drawdown test was not conducted since the spacing of the observation wells were already as close as was practicable.

Completion and well design information for all of the wells at Site 3 is supplied in Table 5. Pumping well PW20691 was drilled to a depth of 25.8 feet, is open to the Rocky Flats Alluvium from 3.8 to 25.0 feet below ground surface, and has a 2-inch casing/screen diameter inside a 10-inch borehole. The pumping well was not cored or logged; however, the lithology is assumed to be similar to observation well OB20791 located 5.54 feet to the north. Well construction and lithologic information for all wells is given in Appendix A. Well development information for the new wells is also included in Appendix A.

Observation well OB20791 was drilled to a depth of 36.5 feet and is open to the Arapahoe Formation claystone from 28.7 to 34.5 feet below ground surface. Observation well OB20591 was not cored but is assumed to have a lithology similar to observation wells OB20791 and 1787, that is, gravelly sand with some clay or a sandy clayey gravel.

The saturated thickness (water level to top of bedrock) ranged from 12.77 feet in well 1787 to 11.77 feet in well OB20591. The saturated thickness in the pumping well was intermediate at 12.04 feet. Pre-test static water levels were between 12 to 12.5 feet below ground surface in the alluvial wells; the water level in the claystone well, OB20791, was at 26.62 feet below ground surface.

A geologic cross section was constructed to illustrate the lithologic and hydrogeologic setting at Site 3 (Figure 61).

7.2 DATA COLLECTION

Four wells used in the pumping test were configured for electronic data logging of water levels. The site was configured similar to that for the pumping test at Site 1. A Grundfos submersible pump, powered by a 230-volt gasoline-powered generator, was used for the step drawdown test. However, attempts to use the submersible pump and a valved-down diaphragm pump were unsuccessful at the low pumping rates required for the pumping test; therefore, a peristaltic pump was used. The transducer cable and drawdown tube were hung at about 20 feet from TOPC. The end of the peristaltic pump intake tubing was placed very close to the bottom of the well, about 24 feet from the TOPC. A diesel generator provided power to the pump.

7.2.1 Step-drawdown Test

As set forth in SOP GW.08 (EG&G, 1991d), an evaluation of the expected yield using a step-drawdown test was performed. Results of this test and three aborted pumping tests were used to estimate a pumping rate, the duration of the effects of wellbore storage and the radius of influence (Appendix B). Hydraulic conductance was also estimated so that the maximum drawdown in the pumping well could be predicted. Results of this test indicated that all observation wells would be within the drawdown cone at a pumping rate of 0.06 gpm and that wellbore storage might be significant. A maximum drawdown of 3.0 feet (25% of the saturated thickness of 12.04 feet) was not expected to occur for the duration of the pumping test.

7.2.2 Pumping Test

The constant-rate pumping test at Site 3 was initiated on May 20, 1992, at 1552 hours. With the aid of synchronized stop watches, the pump and the data loggers were started simultaneously. The pump was shut down at 0940 hours on May 26 (8268 minutes after pumping started), concluding the drawdown phase of the test. Recovery and background water-level trends were recorded for an additional 8446 minutes. The test concluded at 0834 hours on June 1, 1992. Drawdown, recovery, and antecedent water-level trends are presented in Appendix C.

The wells at Site 3 include PW20691 as the pumping well, 1787 and OB20591 as alluvial observation wells, and OB20791, which is open to Arapahoe Formation claystone, as a bedrock observation well. Water-level data for these wells, immediately prior to pumping, is presented in Table 5. Water levels in the well field were between 12 and 12.5 feet below ground surface in the alluvial wells and 26.6 feet below ground surface in underlying claystone bedrock. These levels were measured by hand using tapes referenced to the TOPC.

The maximum drawdown observed during the test was 2.72 feet in the pumping well (Figure 62), 1.08 feet in well 1787, and 1.13 feet in well OB20591. Recovery and post-pumping background water-level data were collected for almost 6 days. Based on recovery data for well OB20591, there is a strong background water-level trend. This trend is apparent in the recovery hydrograph of the pumping well (Figure 62). The average decline in water level is 0.1 foot/day. This same trend is evident in the recovery data for wells 1787 and OB20591.

7.2.2.1 Factors Affecting The Test

Fluctuating discharge and inability to sustain a low pumping rate with the Redi-Flo II pump necessitated the use of a peristaltic pump. The test configuration used two Geotech peristaltic pumps in series with 3/8-inch diameter riser discharge tubing. During discharge only one pump was used with the second in series back-up mode. This enabled alternation of pumps for cool-down and flexible tubing change. Pump changeover was accomplished in less than 2 seconds. Power supply was continuous throughout the drawdown phase.

Pumping discharge was measured throughout the period of pumping. Initial flow rates were 0.056 gpm. The flow rate range was between 0.048 and 0.065 gpm, resulting in an average of 0.056 gpm.

7.2.2.2 Quality Assurance

Manual measurements of the water levels in the well were used to verify transducer data. Minor fluctuations were observed in transducer data from the observation wells which were also adjusted to hand measurements. Transducer data and manual measurements for the wells in Site 3 are included in Appendix C.

The results of data analysis methods for constant-rate drawdown aquifer tests are most accurate when discharge rates are constant during pumping. The changeover of pumps and subsequent adjustment of rate had an impact on the drawdown curve as can be seen in Figure 62. However, these fluctuations, when taken in context of the entire curve, can be neglected during analysis.

The strong background water-level decline during the test interval necessitates adjustment of both the drawdown and recovery data for the wells at Site 3. Adjustment by a factor of about 0.1 foot per day was used.

7.2.3 Water Quality Parameters

Discharge water was periodically checked using appropriate on-site instruments to measure pH, SC, and temperature. The pH ranged from 6.92 to 7.8. The SC of the water was measured using a meter calibrated at 1,000 µS/cm at 25°C. Initial measurements ranged from 723 to 790 µS/cm and represent those of *in situ* formation water discharged during the pumping phase prior to injection of KBr tracer at approximately 75 hours into pumping.

7.2.4 Tracer Test

A radial flow induced gradient tracer test was conducted at Site 3 using well OB20591 as the injection well and well PW20691 (the pumping well) as the detection well (Figure 60). To assure a constant gradient between the injection well and the detection well, drawdown data for the two wells was evaluated for steady-state conditions necessary for the analysis of radially converging tracer tests (Sauty, 1980). After approximately 75 hours of pumping, drawdown data from well OB20591 and well PW20691 indicated that the wells were at steady-state. The test was begun at 1852 hours on May 23, 1992, and continued until the pump was shut down at 0940 hours, May 26, 1992, or a period of 62.8 hours. KBr was also used as the tracer at Site 3 for the same reasons cited for Site 1. Water-level and SC data were collected throughout the tracer test to monitor the hydraulic gradient.

7.2.4.1 Introduction of Tracer to the Aquifer

An initial mass of 5.5 pounds of reagent grade KBr was dissolved in 1.5 gallons of distilled water. Complete mixing of the solute in the casing was accomplished by the same method used at Site 1, discussed in Section 5.2.4.1, that is, with tubing and a funnel. The solute was added to the middle portion of the screened interval, and mixing in the well was accomplished by rapidly raising and lowering the tubing in the well.

7.2.4.2 Procedure for Collection of Field Data

Prior to the introduction of the tracer, the SC of the pumped water was measured to establish a background reading. A Fischer-Scientific Model 152 Specific Conductance meter, Model 152, was calibrated using a standard solution as specified by the manufacturer. After introduction of the tracer to the injection well, SC measurements of pumped water (from the detection well) were made periodically until the readings indicated a rise in the SC. At this point in time, SC measurements were made every 30 minutes through the peak of conductance. Samples were collected for later laboratory measurement of bromide ions. The field SC peak was detected in well PW20691 at 1401 hours on May 24 (Figure 63). Field values are given in Appendix D.

7.2.4.3 Procedure for Collection of Laboratory Data

The response of the Orion Model SA250 pH meter was used to measure the bromide concentration in mV of the samples collected in the field. The results were then compared with a prepared calibration curve to determine corresponding bromide concentration. The results and the curve are presented in Appendix D.

The method of preparation of the calibration solutions and the measurement of bromide ions is the same as that for Site 1, discussed in Section 5.2.4.3. Field SC values peaked about 13 hours earlier than laboratory analyzed Br^- concentrations which reached a high in a sample collected at 0120 hours on May 25 (Figure 63). The reason for the conflicting results has not been determined.

All samples from Site 1 were re-tested for Br^- and SC, resulting in the same values derived from the first analysis. Again, the field SC peaked at the same time as the laboratory analyzed values of SC and Br^-. Although this did not explain the anomalous readings for Site 3, it did demonstrate that the instrumentation was working correctly.

7.3 ANALYSIS OF PUMPING TEST DATA

7.3.1 Considerations

Wellbore storage effects for pumping well PW20691 were evaluated using the Shafer method (1978) used for the other two sites. Since the hydraulic conductivity of the filter pack is much greater than that of the surrounding formation, the effective radius of the filter pack (r_{fp}) was added to the equation as follows:

$$t_c = \frac{375(r_c^2 + r_{fp}^2 - r_p^2)}{T}$$

$$\text{where } r_{fp} = \sqrt{(r_b^2 - r_c^2)0.35}$$

where r_b = radius of the borehole in feet (0.417)

0.35 = effective porosity of filter pack

Using a transmissivity of 30.9 gpd/ft and an r_{fp} of 0.24 feet, t_c is 0.74 days, or 1069 minutes. This was taken into consideration in analysis of the data.

Delayed yield in the observation wells of Site 3 using the method of Walton (1962) and assuming a specific yield of 0.1, a hydraulic conductivity of 2.56 gpd/ft^2, and an average thickness of 12 feet, suggests the time required for the effects of delayed yield to be negligible is 17.5 days.

Pumping at Site 3 lasted for only 5 days; delayed yield is not apparent on the hydrograph of well PW20691 (Figure 62).

No evidence of boundary effects were seen in the drawdown data of the wells at Site 3. The pumping well, PW20691, is fully penetrating. Precipitation did occur during the test (Figure 13), but recharge is not evident, especially in light of the strong background water-level decline.

Recovery and background data for well PW20691 indicate declining background water levels (Figure 64). Therefore, it is necessary to extrapolate the water-level trend prior to pumping or after recovery through the pumping period (Walton 1991) and determine the resulting drawdowns had background water-level changes not occurred. In the case of Site 3, post-pump test water-level trends were used to correct the observed drawdowns as follows:

- A linear plot of recovery data was generated for each well. Plots showed a linear trend for the post-recovery water-level readings. Each well showed a linear decrease in water-level readings 2000 minutes after pumping stopped.

- A linear least squares regression was performed to determine water-level decline as a function of time. The results are as follows:

	Well #1787	Well #20591	Well #20691
Water-Level Decrease (ft/min)	7.27E-5	7.24E-5	7.33E-5
R Squared	.995	.995	.994

- Water-level observations were corrected prior to analysis by subtracting the background water-level trend from the depth to water observations during the pumping test and recovery period.

7.3.2 Analytical Results

The well parameters used to analyze the test data for each well are provided in Table 6. The pumping rate used for analysis of the wells at Site 3 is 0.056 gpm. The saturated thicknesses used for calculations are given in Table 6 and represent the difference between the pre-test static water level and the top of bedrock. The reliability of the data collected during this test is compromised by several factors, including the very low pumping rate, changeover of pumps requiring pumping rate adjustment, the very small radial distances, and the strong background decline in water level. Additionally, at each pump changeover, the rate was slow initially, then sped up as the tubing became more pliable.

The results of the three methods of analysis are compiled in Table 6. Figures 65 through 73 present the graphed results of the three analytical methods: the Cooper-Jacob straight line analysis, the Theis analysis, and the Theis recovery analysis. Values of drawdown were corrected to s' for the Theis and Cooper-Jacob analyses. The hydraulic conductivity obtained from the Theis analysis of drawdown at well OB20591 is about an order of magnitude less than that obtained from wells 1787 and OB20591. This difference may be a result of aquifer heterogeneities. The hydraulic conductivity of PW20691 is consistent with that derived from the step test recovery data (Appendix B).

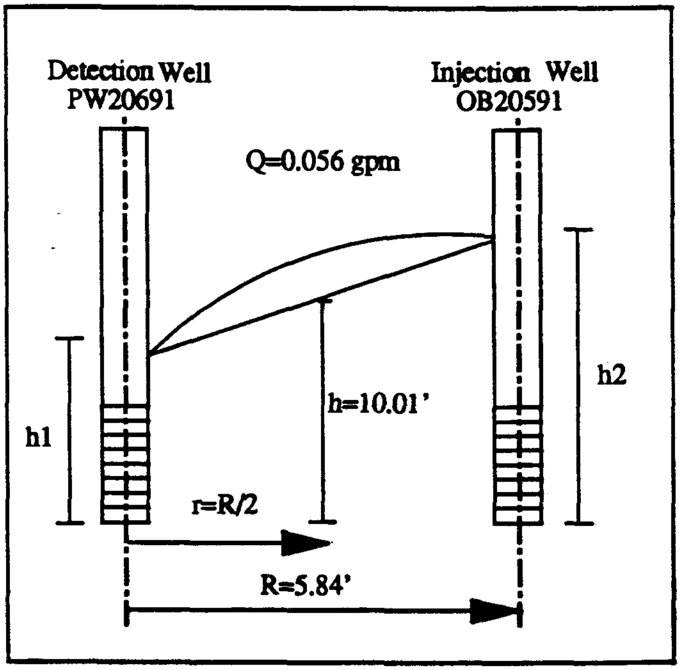
Storativity values are surprisingly high (Table 6) and are borderline characteristic of unconfined aquifers. This indicates that delayed yield would have already occurred, which is not supported by the estimates provided above.

The data required correction for analysis (Appendix C) and were adversely affected by the factors mentioned above. The hydraulic conductivity of the material is very low and it responds to pumping in a manner similar to ordinary porous media. However, some of the deviation from ideal behavior may be related to the effect of fractures and delayed release of water from storage in the clayey materials. Additionally, the strong background water-level decline and the failure of the recovery curve to attain the pre-pumping test status water-levels suggests the aquifer may be limited in extent.

Observation well OB20791, open to the claystone of the Arapahoe Formation, did not respond in a characteristic manner. Drawdown and recovery curves (Figure 74) show an overall increase in the water level during pumping followed by a continued increase in water levels during recovery. The claystone is clearly not part of the uppermost hydrostratigraphic unit as it does not respond to the pumping of the alluvium with drawdown. The pre-test elevation of the water level in the claystone was over 14 feet lower than that of the alluvium. This reflects a condition of disequilibrium and indicates that the degree of interconnectedness is small. This disequilibrium may represent incomplete recovery after development.

7.4 ANALYSIS OF TRACER TEST DATA

Tracer test data for Site 3 were analyzed using the same method as that used for Site 1. Type curves were generated (Figure 75) for Peclet numbers of 1, 3, 10, 30, 100, 300, and 1000. Laboratory analyzed values of Br^- concentration and field values of SC were plotted with dimensionless concentration versus real time (t) on the same scale as the type curves (Figures 76 and 77). The Br^- concentration could not be successfully fit to the type curves. Parameters used for the Site 3 calculations are provided in the schematic below.



The plot of field SC was curve-matched to a Peclet number of 20 and a *t* of 0.95 days. This yields a longitudinal dispersivity of 0.29 and a kinematic porosity of 1%. This value of effective (kinematic) porosity is unrealistically low.

The poor results of the Br^- and SC tracer test data are consistent with the fact that the curve of the laboratory analyzed Br^- concentration is much broader than that generated by the SC data. Additionally, the peak arrival times are widely divergent with 19.2 hours after injection for the SC and 30.5 hours for the Br. As discussed in Section 7.2.4.3, it is not known why this occurred.

Of the two sets of data, the laboratory analyzed Br^- concentrations are believed to be more reliable. However, all of the data acquired for the Site 3 tracer test should be used with caution.

8.0 CONCLUSIONS

Three pumping tests, one slug test, and two tracer tests were conducted on the Rocky Flats Alluvium and the Arapahoe Formation uppermost sandstone in the OU2 area between April 28 and June 26, 1992. Results of the tests (Table 7) serve to confirm the presence of heterogeneities in both the alluvium and the bedrock.

The tests characterized the hydrogeological scenarios as set forth in TM3 and were conducted as planned at Sites 1 and 3. The Site 2 test was redesigned as a result of pumping well abandonment and the unexpected presence of a claystone layer at the alluvium-bedrock unconformity. The presence of the claystone between the alluvium and the sandstone is inconsistent with the test scenario of a direct hydraulic connection between the alluvium and the sandstone. A pumping test of the alluvium was conducted. Observation of the bedrock wells within the test area showed a clear response to pumping of the alluvium and indicated a significant hydraulic interconnection. Additionally, slug testing of bedrock well OB20191 affected the water level in the closest alluvial well OB20291, underscoring a hydraulic interconnection.

The pumping test of the alluvium at Site 3 did not produce a response in a well completed in the Arapahoe claystone indicating a lack of a significant hydraulic connection. The claystone is clearly not part of the uppermost hydrostratigraphic unit, as it did not respond to the pumping of the alluvium with drawdown.

The hydraulic conductivities of the alluvium vary from the 10^{-3} to 10^{-4} cm/sec range at Site 2 to 10^{-4} cm/sec at Site 3, representing the textural heterogeneities of the sites. Even though the materials of both sites consist predominantly of clayey sands and clayey gravels, a minor well-graded gravel near the base of the alluvium at Site 2 may be responsible for the site's higher hydraulic conductivities.

Tests conducted on the uppermost Arapahoe Formation sandstone produced hydraulic conductivities that vary by two orders of magnitude. A pumping test performed at Site 1 yielded values of hydraulic conductivities in the range of 10^{-4} cm/sec for the well-sorted sandstones. Conversely, a slug test of well OB20191 at Site 2 produced a hydraulic conductivity of 4.88×10^{-6} cm/sec for the clayey sandstones. The difference of the two orders of magnitude is consistent with the wide range of clay content found in the sandstones representative of each site.

Tracer testing of the sandstone at Site 1 and the alluvium at Site 3 provided estimates of longitudinal dispersivity and kinematic porosity (Table 7). The Site 1 test produced consistent results for both field and laboratory-analyzed data. The Site 3 test may well have been impacted by adverse field conditions including a low pumping rate and a declining water table. The field and laboratory-analyzed data yield inconsistent results and should be viewed with skepticism. The very small distances between the injection and detection wells at both sites is apparent in the low values of the scale-dependent longitudinal dispersivity.

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Table 1

Site No. 1 Well Specifications

Well Number	3587	OB21091	PW20891	OB20991	3687
Purpose	alluvial observation	bedrock observation	bedrock pumping	bedrock observation	bedrock observation
Easting, ft	2,087,267.79	2,087,282.14	2,087,285.03	2,087,286.68	2,087,295.04
Northing, ft	749,974.44	749,997.08	749,976.87	749,970.90	749,979.12
Elevations (ft, MSL)					
TOPC[1)]	5,951.97	5,950.23	5,952.02	5,951.61	5,951.72
Top of 6-inch pad[2)]	5,949.96	5,948.57	5,949.85	5,949.78	5,949.67
Ground Surface	5,949.46	5,948.07	5.949.35	5,949.28	5,949.04
Depth from Ground Surface	9.1	11.0	ND	9.0	7.4
Bedrock unconformity	3.0	17.0	18.0	18.5	18.1
Top of filter pack	9.75	63.8	64.0	65.0	63.6
Base of filter pack	--dry--	27.55	27.13	27.54	27.35
Water level[3)]	--dry--	31.04	34.18	33.24	31.57
Water level, final[4)]	14.4	68.0	64.0	70.0	74.5
Total depth, ft-gs					
Screened lithology	Qrf alluvium	Ka sandstone	Ka sandstone	Ka sandst, claystone	Ka sandst, siltstone
Distance to pumping well, ft	16.95	20.98	0.0	5.69	10.73
Saturated thickness at start of pumping	NA	33.15	30.61[6)]	28.06	33.15
Org. vap. @ wellhead ppm (breathing zone)	NA	0.0	0.0	0.0	0.0

1) Top Of Protective Casing used as water level datum.

2) During 1991 well drilling and logging all points below ground surface were referenced to ground surface with a datum of 0.0 feet. Following well installation at 0.5-foot thick concrete pad was laid then subsequently land surveyed for elevation by Merrick, 1992. These measurements were reported as "ground" and are listed above as top of 6-inch well pad.

3) Water level/depth indicated is just prior to initiation of pumping at 1730 hours on April 28, 1992.

4) Water level/depth at termination of pumping on May 4, 1992 at 1723 hours.

5) Saturated thicknesses are based on total feet of permeable units.

6) Assumed value based on average of saturated thicknesses in 3687 and OB20991.

Table 2

Site 1 - Analytical Results

WELL NUMBER	3687 Bedrock	OB20991 Bedrock	OB21091 Bedrock	PW20891 Bedrock
Saturated Thickness (ft) (saturated filter pack)	36.25	36.46	37.45	36.87
Saturated Thickness (ft) (saturated permeable units)	33.15	28.06	33.15	30.61
Pumping Rate (gpm)	1.62	1.62	1.62	1.62
Distance to Pumping Well (ft)	10.73	5.69	20.98	0.42
COOPER - JACOB ANALYSIS				
Slope (ds/dlog(t))	1.254	1.164	1.235	1.415
Y Intercept	-0.863	0.546	-0.624	1.419
X Intercept	4.879	0.339	3.203	0.099
Coefficient of Determination (R^2)	0.999	0.913	0.998	0.855
t (min for U < .1)	27.44	1.91	18.02	0.56
t (min used in calculation)	30	100	40	100
U	0.091	0.002	0.045	0.001
Transmissivity (ft^2/min)	3.161E-02	3.405E-02	3.209E-02	2.802E-02
Transmissivity (gpd/ft)	340.5	366.8	345.7	301.8
Hydraulic Conductivity (cm/sec)(filter pack)	4.43E-04	4.744E-04	4.353E-04	3.860E-04
Hydraulic Conductivity (cm/sec) (permeable units)	4.844E-04	6.164E-04	4.918E-04	4.650E-04
Hydraulic Conductivity (ft/min)	7.903E-03	8.512E-03	8.023E-03	7.004E-03
Storage Coefficient	3.014E-03	8.030E-04	5.254E-04	3.606E-02
THEIS ANALYSIS (AQTESOLV)				
Transmissivity (ft^2/min)	3.118E-02	2.943E-02	3.359E-02	3.022E-02
Transmissivity (gpd/ft)	335.9	317.0	361.9	325.5
Hydraulic Conductivity (cm/sec)(filter pack)	4.370E-04	4.101E-04	4.556E-04	4.164E-04
Hydraulic Conductivity (ft/min)	0.000860138	0.000807186	0.000896929	0.00819637
Hydraulic Conductivity (cm/sec) (permeable units)	4.778E-04	5.328E-04	5.147E-04	5.972E-04
Storage Coefficient	4.296E-03	1.535E-03	5.128E-04	1.254E-02
THEIS RECOVERY ANALYSIS				
Slope (ds/dlog(t/t'))	1.328	1.501	1.303	NA
Y Intercept	0.319	-0.310	-0.141	NA
Coefficient of Determination (R^2)	0.999	0.995	0.997	NA
t (min for U < .1)	29.1	2.5	19.0	NA
t (min used in calculation)	40	9	72	NA

Table 2 - continued

Site 1 - Analytical Results

WELL NUMBER	3687 Bedrock	OB20991 Bedrock	OB21091 Bedrock	PW20891 Bedrock
THEIS RECOVERY ANALYSIS				
U (using S from Cooper - Jacob)	0.073	0.027	0.026	NA
U (using S from Theis)	0.104	0.052	0.025	--
Transmissivity (ft^2/min)	2.985E-02	2.641E-02	3.042E-02	--
Transmissivity (gpd/ft)	321.6	284.5	327.7	--
Hydraulic Conductivity (cm/sec)(filter pack)	4.183E-04	3.68E-04	4.126E-04	--
Hydraulic Conductivity (ft/min)	8.235E-04	7.242E-04	8.122E-04	--
Hydraulic Conductivity (cm/sec) (permeable units)	4.184E-04	3.679E-04	4.126E-04	--
Storage Coefficient	NA	NA	NA	--

Tab[illegible]

Site No. 2 Well Specifications

Well Number	5691	11391	11491	12491	PW20091	OB20191	OB20291	OB20391	OB20491	OB21191
Purpose	alluvial monitor	borehole	alluvial monitor	bedrock monitor	alluvial pumping	bedrock observation	alluvial observation	bedrock observation	alluvial observation	bedrock observation
Easting, ft	2,087,620.69	2,087,615.12	2,087,628.36	2,087,628.36	2,087,602.73	2,087,610.42	2,087,612.42	2,087,606.17	2,087,612.42	2,087,598.92
Northing, ft	750,053.14	750,072.20	750,034.63	750,058.25	750,055.58	750,061.24	750,052.41	750,050.76	750,052.41	750,059.98
Elevations (ft MSL)										
TOPC[1]	5,949.30	NA	5,950.01	5,948.60	5,948.80	5,948.79	5,948.91	NA	5,948.47	5,948.79
Top of 6-inch pad	5,947.61	NA	5,948.22	5,946.84	5,947.03	5,946.93	5,947.19	NA	5,947.23	5,946.85
Ground Surface[2]	5,947.11	5,946.01	5,947.72	5,946.34	5,946.53	5,946.43	5,946.69	5,946.96	5,946.73	5,946.35
Depth from Ground Surface										
Bedrock unconformity	35.2	37.5	ND	30.0	31.7	33.1	33.1	36.0	31.6	31.7
Top of filter pack	23.0	NA	8.0	41.7	NA	33.9	16.0	NA	14.6	29.0
Base of filter pack	35.2	NA	25.3	60.0	NA	59.0	33.3	NA	32.1	58.0
Water level[3]	22.25	NA	22.9	22.14	NA	22.06	22.26	NA	22.77	21.95
Water level, final[4]	23.09	NA	23.22	22.37	NA	22.39	26.84	NA	23.31	22.41
Total depth, ft-gs	42.6	66.0	27.3	65.0	57.0	76.0	35.6	76.6	32.9	58.0
Screened lithology	Qrf	NA	Qrf	Ka sandstone	NA	Ka sandstone	Qrf	NA	Qrf	Qrf, Ka sandstone
Distance to pumping well, ft	8.3	20.0	23.9	24.8	NA	9.1	NA	NA	11.8	15.5
Saturated thickness at start of pumping[5]	12.89	NA	12.89[6]	31.5	NA	12.8	10.84	NA	8.82	31.5 + 9.75[7]
Org. vap. @ wellhead ppm (breathing zone)	0	NA	0	0	NA	0	0	NA	0	0

1) Top Of Protective Casing (TOPC) used as water level datum.

2) During 1991 well drilling and logging all points below ground surface were referenced to ground surface with a datum of 0.0 feet. Following well installation at 0.5-foot thick concrete pad was laid then subsequently land surveyed for elevation by Merrick, 1992. These measurements were reported as "ground" and are listed above as Top of 6-inch well pad.

3) Water level/depth indicated is just prior to initiation of pumping at 0917 hours on June 23, 1992.

4) Water level/depth at termination of pumping on June 25, 1992 at 0805 hours.

5) Alluvial saturated thicknesses reflect the difference between static water level and top of bedrock. Bedrock thicknesses reflect the total footage of permeable units open to the filter pack.

6) Assumed similar to 5691.

7) Assumed similar to 12491; open to bedrock and alluvium.

Table 4

Site 2 - Analytical Results

WELL NUMBER	11491 Alluvial	5691 Alluvial	OB20491 Alluvial	OB20291 Alluvial
Saturated Thickness (ft)	12.89	12.89	8.82	10.84
Pumping Rate (gpm)	0.35	0.35	0.35	0.35
Distance to Pumping Well (ft)	23.88	8.30	11.77	0.42
COOPER - JACOB ANALYSIS				
Slope (ds/dlog(t))	0.186	0.190	0.138	0.457
Y Intercept	-0.376	-0.129	-0.093	0.218
X Intercept	105.035	4.789	4.762	0.333
Coefficient of Determination (R^2)	0.970	0.904	0.904	0.985
t (min for U < .1)	590.82	26.94	26.79	1.87
t (min used in calculation)	200	50	20	550
U	0.295	0.054	0.134	0.000
Transmissivity (ft^2/min)	4.599E-02	4.510E-02	6.223E-02	1.875E-02
Transmissivity (gpd/ft)	495.4	485.8	670.3	202.0
Hydraulic Conductivity (cm/sec)	1.813E-03	1.777E-03	3.584E-03	8.789E-04
Hydraulic Conductivity (ft/min)	3.568-03	3.499E-03	7.055E-03	1.730E-03
Storage Coefficient	1.906E-02	7.055E-03	4.813E-03	8.100E-02
THEIS ANALYSIS (AQTESOLV)				
Transmissivity (ft^2/min)	4.072E-02	4.638E-02	5.382E-02	1.736E-02
Transmissivity (gpd/ft)	438.6	499.6	579.7	187.2
Hydraulic Conductivity (ft/min)	3.159E-03	3.598E-03	6.102E-03	1.601E-03
Hydraulic Conductivity (cm/sec)	1.605E-03	1.828E-03	3.100E-03	8.136E-04
Storage Coefficient	2.483E-02	7.325E-03	6.934E-03	9.893E-02

Table 5

Site No. 3 Well Specifications

Well Number	1787 Alluvial	OB20591 Alluvial	PW20691 Alluvial	OB20791 Bedrock
Purpose	observation	observation	pumping	observation
Easting, ft	2,086,308.03	2,086,316.41	2,086,317.24	2,086,317.61
Northing, ft	749,415.25	749,404.73	749,410.51	749,416.04
Elevations (ft, MSL)				
TOPC[1)]	5,970.60	5,969.83	5,969.91	5,969.66
Top of 6-inch pad	5,968.01	5,968.01	5,968.09	5,967.90
Ground surface[2)]	5,967.51	5,967.51	5,967.59	5,967.40
Depth from Ground Surface				
Bedrock unconformity	24.9	24.2	24.5	24.5
Top of filter pack	2.9	3.6	3.8	28.7
Base of filter pack	25.5	24.6	25.0	34.5
Water level, initial[3)]	12.23	12.43	12.46	26.62
Water level, final[4)]	13.31	13.56	15.18	26.36
Total depth, ft-gs	30.3	24.6	25.8	36.5
Water depth, May 26, 1992 @ 0940 hours	16.40	15.83	17.50	28.62
Screened lithology	Qrf	Qrf	Qrf	Ka clayst
Distance to pumping well, ft	10.25	5.84	0.0	5.54
Saturated thickness at start of pumping[5)]	12.77	11.77	12.04	NA
Org. vap. @ wellhead ppm (breathing zone)	0.0	0.0	0.0	0.0

1) Top Of Protective Casing used as water level datum.

2) During 1991 well drilling and logging all points below ground surface were referenced to ground surface with a datum of 0.0 feet. Following well installation at 0.5-foot thick concrete pad was laid then subsequently land surveyed for elevation by Merrick, 1992. These measurements were reported as "ground" and are listed above as top of 6-inch well pad.

3) Water level/depth indicated is just prior to initiation of pumping at 1552 hours on May 20, 1992.

4) Water level/depth at termination of pumping on May 26, 1992 at 0940 hours.

5) Saturated thickness reflect difference between top of bedrock and the static water level.

Table 6
Site 3 - Analytical Results

WELL NUMBER	1787 Alluvial	OB20591 Alluvial	PW20691 Alluvial
Saturated Thickness (ft)	12.77	11.77	12.04
Pumping Rate (gpm)	0.056	0.056	0.056
Distance to Pumping Well (ft)	10.25	5.84	0.42
COOPER - JACOB ANALYSIS			
Slope (ds/dlog(t))	0.306	0.369	0.443
Y Intercept	-0.772	-0.864	0.154
X Intercept	335.349	220.769	0.448
Coefficient of Determination (R^2)	0.780	0.462	0.904
t (min for U < .1)	1886.34	1241.82	2.52
t (min used in calculation)	2000	1500	800
U	0.094	0.083	0.000
Transmissivity (ft^2/min)	4.480E-03	3.716E-03	3.090E-03
Transmissivity (gpd/ft)	48.3	40.0	33.3
Hydraulic Conductivity (cm/sec)	1.782E-04	1.604E-04	1.304E-04
Hydraulic Conductivity (ft/min)	3.509E-04	3.157E-04	2.566E-04
Storage Coefficient	3.218-02	5.411E-02	1.796E-02
THEIS ANALYSIS (AQTESOLV)			
Transmissivity (ft^2/min)	4.050E-03	3.297E-03	2.866E-03
Transmissivity (gpd/ft)	43.6	35.5	30.9
Hydraulic Conductivity (cm/sec)	1.612E-04	1.423E-04	1.209E-04
Hydraulic Conductivity (ft/min)	3.171E-04	2.801E-04	2.380E-04
Storage Coefficient	4.973E-02	6.870E-02	3.042E-02
THEIS RECOVERY ANALYSIS			
Slope (ds/dlog(t/t'))	0.059	0.069	1.303
Y Intercept	0.235	0.485	-2.931
Coefficient of Determination (R^2)	0.977	0.983	0.904
t (min for U < .1)	366.4	264.4	7.4
t (min used in calculation)	14	18	4.5
U (using S from Cooper - Jacob)	2.617	1.469	0.165
U (using S from Theis)	4.045	2.440	0.279
Transmissivity (ft^2/min)	2.307E-02	1.995E-02	1.052E-03
Transmissivity (gpd/ft)	248.5	215.0	11.3
Hydraulic Conductivity (cm/sec)	9.176E-04	8.612E-04	4.437E-04
Hydraulic Conductivity (ft/min)	1.806E-03	1.695E-03	8.734E-5
Storage Coefficient	NA	NA	NA

Table 7

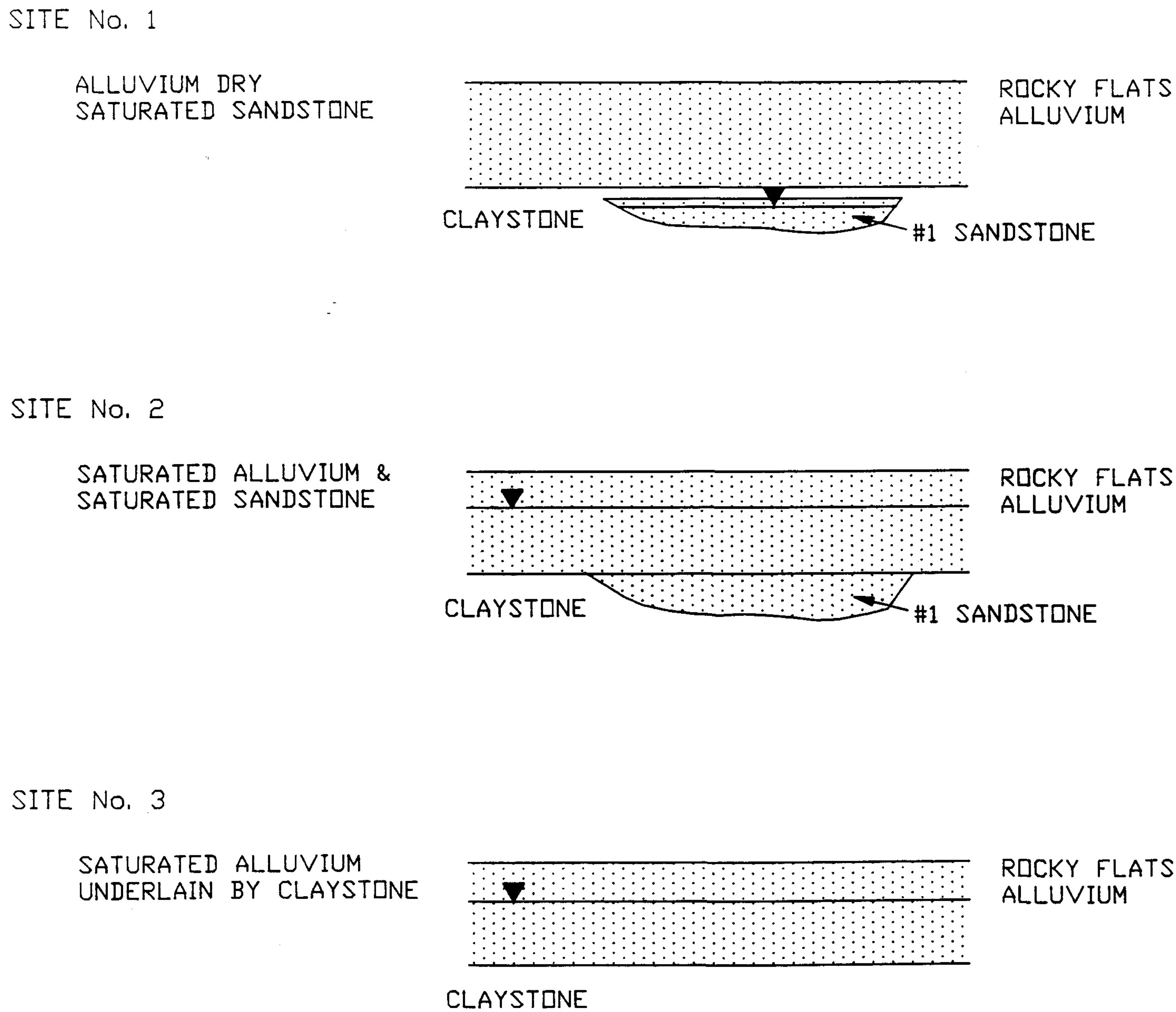
OU2 Aquifer Test Results

	Site 1	Site 2	Site 3
Pumping Test	April 28	June 23	May 20
Slug Test	NA	June 19	NA
Tracer Test	May 2	NA	May 23
Interval Tested	Arapahoe Formation Sandstone	Rocky Flats Alluvium* Arapahoe Formation Sandstone**	Rocky Flats Alluvium
Hydraulic Conductivity (cm/sec)	4.1×10^{-4} to 4.6×10^{-4}	7.1×10^{-4} to 3.1×10^{-3}* 4.88×10^{-6}**	1.6×10^{-4} to 1.2×10^{-4}
Longitudinal Dispersivity, Br^- Data, (ft)	0.19	NA	0.29***
Kinematic Porosity	12%	NA	1%***

* Alluvial Pumping Test

** Bedrock Slug Test

*** Values are not reliable



▼ WATER TABLE

NOTE: NOT TO SCALE

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Rocky Flats Plant, Golden, Colorado

OPERABLE UNIT NO. 2
PHASE II RFI/RI AQUIFER
TEST REPORT

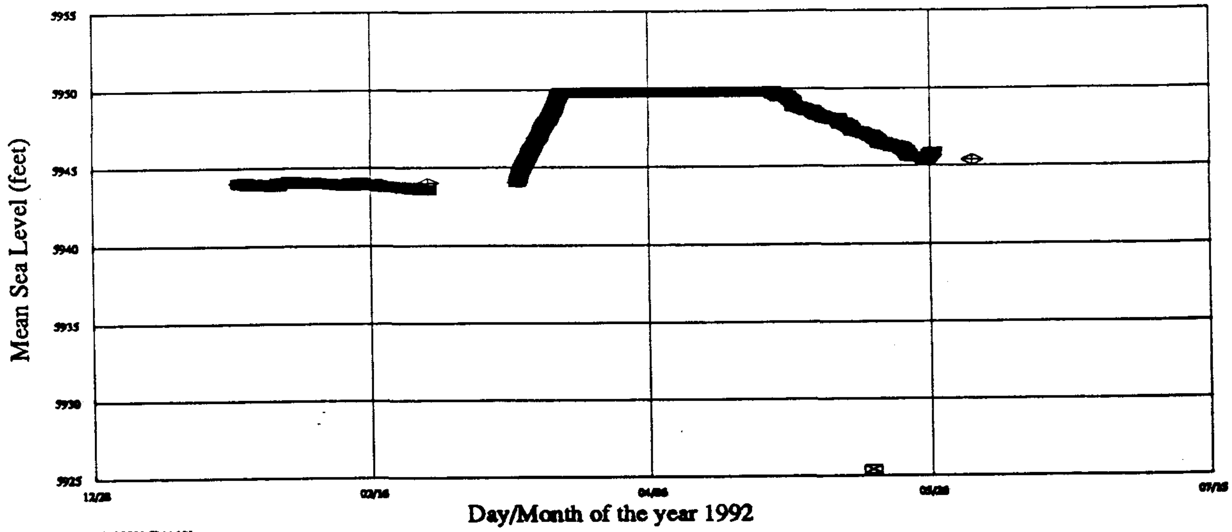
HYDROLOGIC SETTINGS
OPERABLE UNIT 2

FIGURE 3

November, 1992

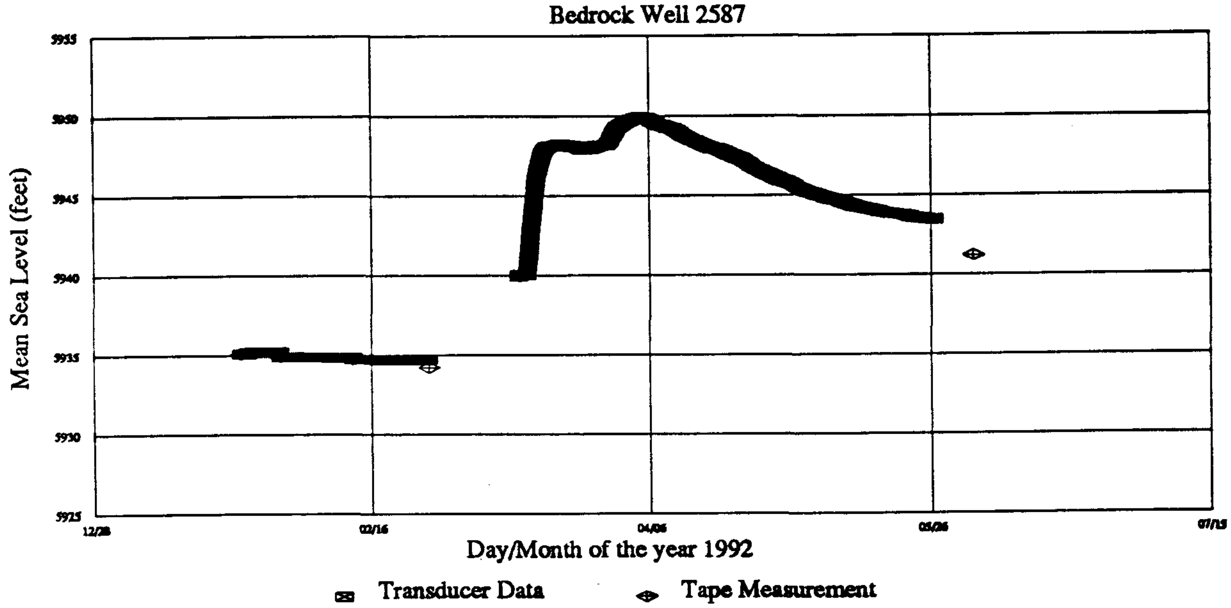
Hydrographs

Alluvial Well 2487



Open Interval 5955.29'-5944.19'

Bedrock Well 2587



Open Interval 5942.48'-5915.58'

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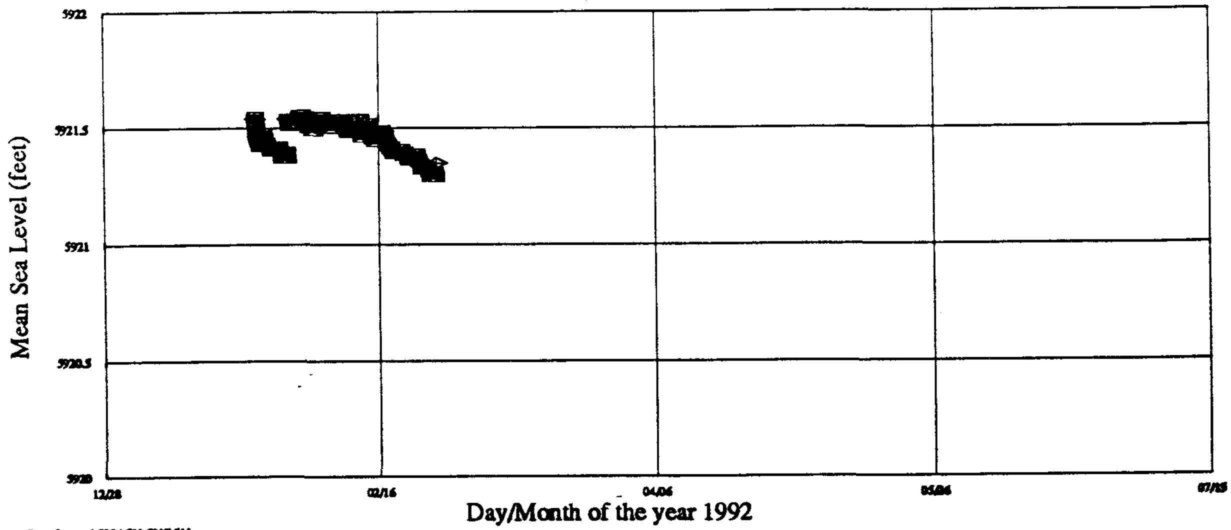
Hydrographs of 2487 and 2587
Background Water Level Trends

FIGURE 4 **NOVEMBER, 1992**

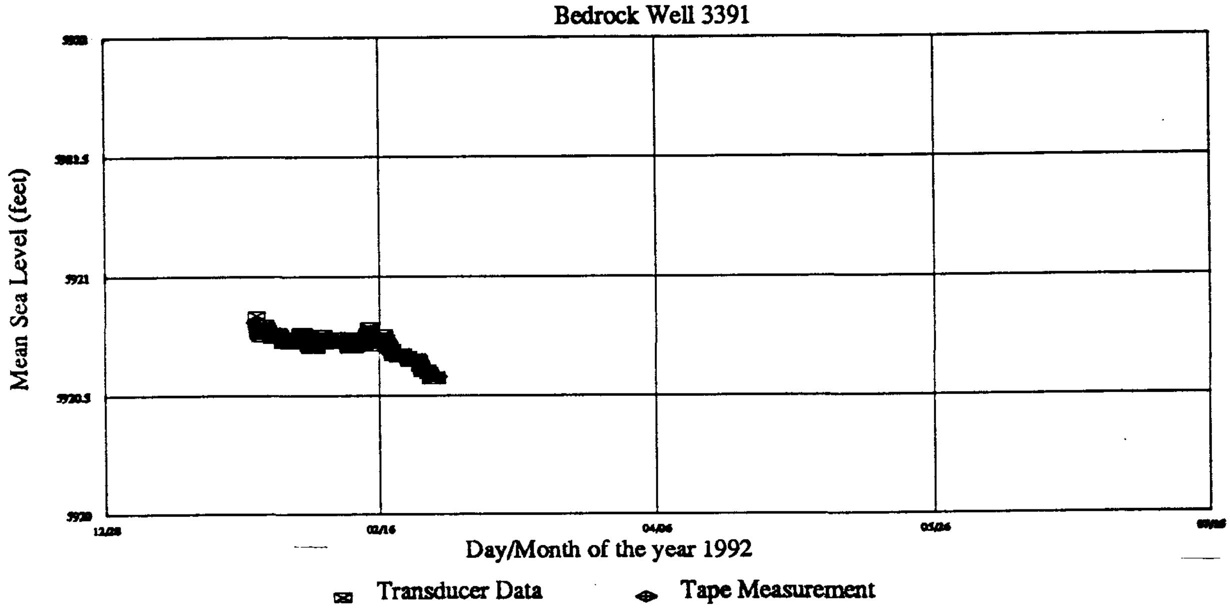
Hydrographs

Alluvial/Bedrock Well 11891



Open Interval 5934.51'-5917.51'

Bedrock Well 3391



Open Interval 5917.64'-5904.54'

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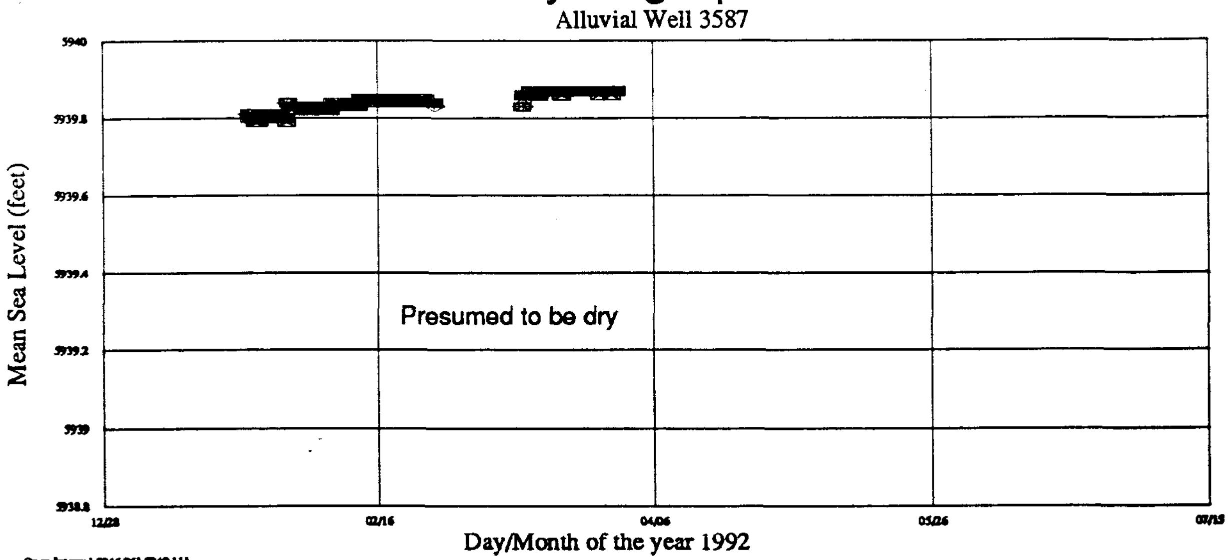
PHASE II RFI/RI AQUIFER TEST REPORT

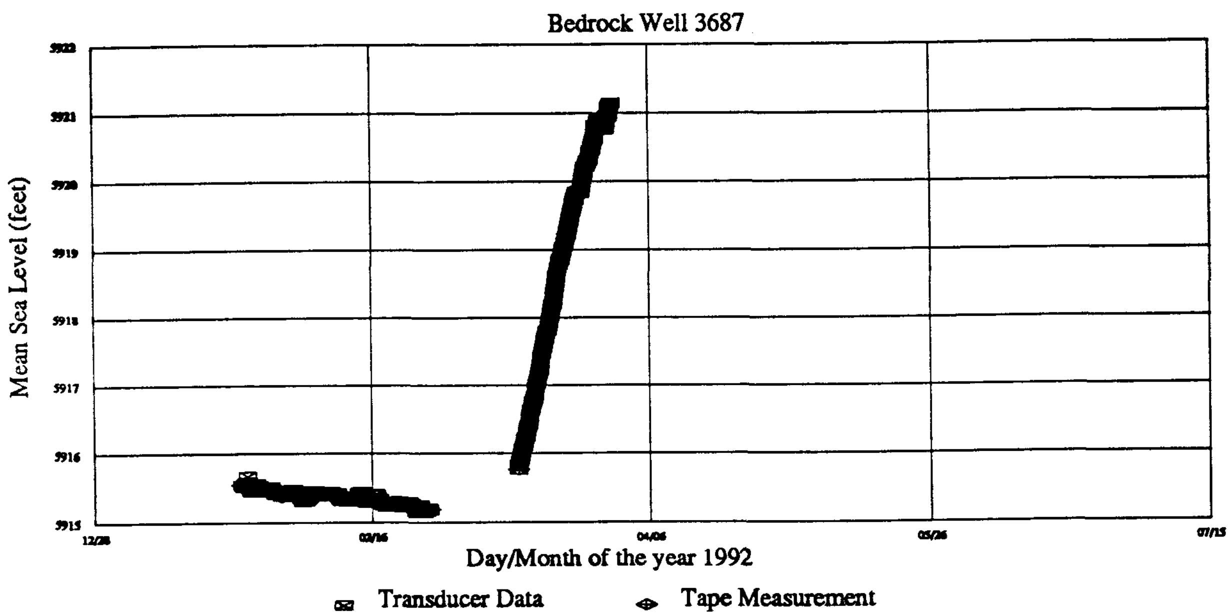
Hydrographs of 11891 and 3391
Background Water Level Trends

FIGURE 5 NOVEMBER, 1992

Hydrographs



Open Interval 5946.96'-5940.11'



Open Interval 5931.57'-5886.10'

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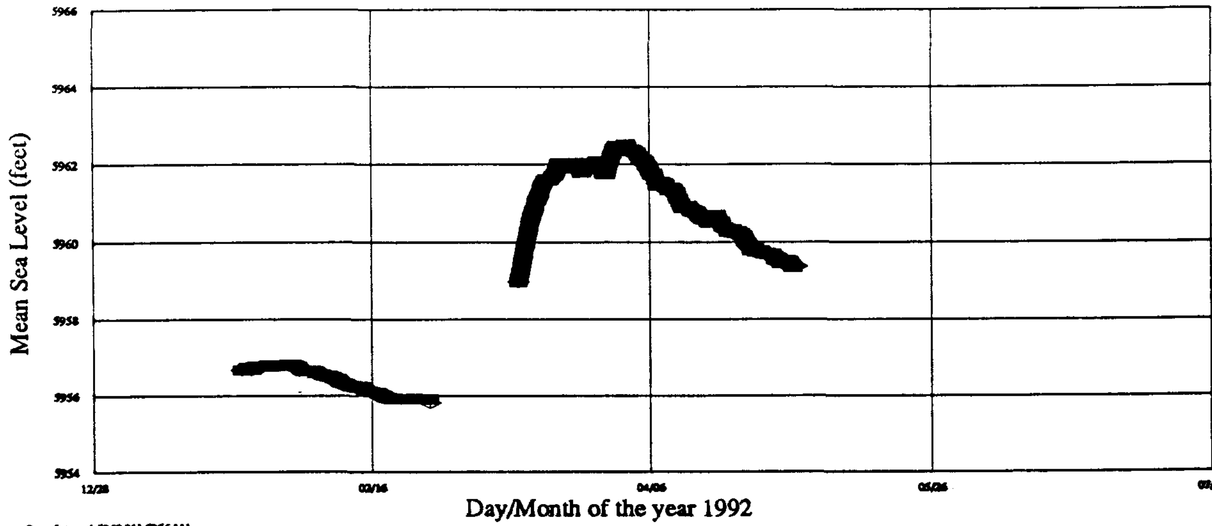
REPORT

Hydrographs of 3587 and 3687
Background Water Level Trends

FIGURE 6 **NOVEMBER, 1992**

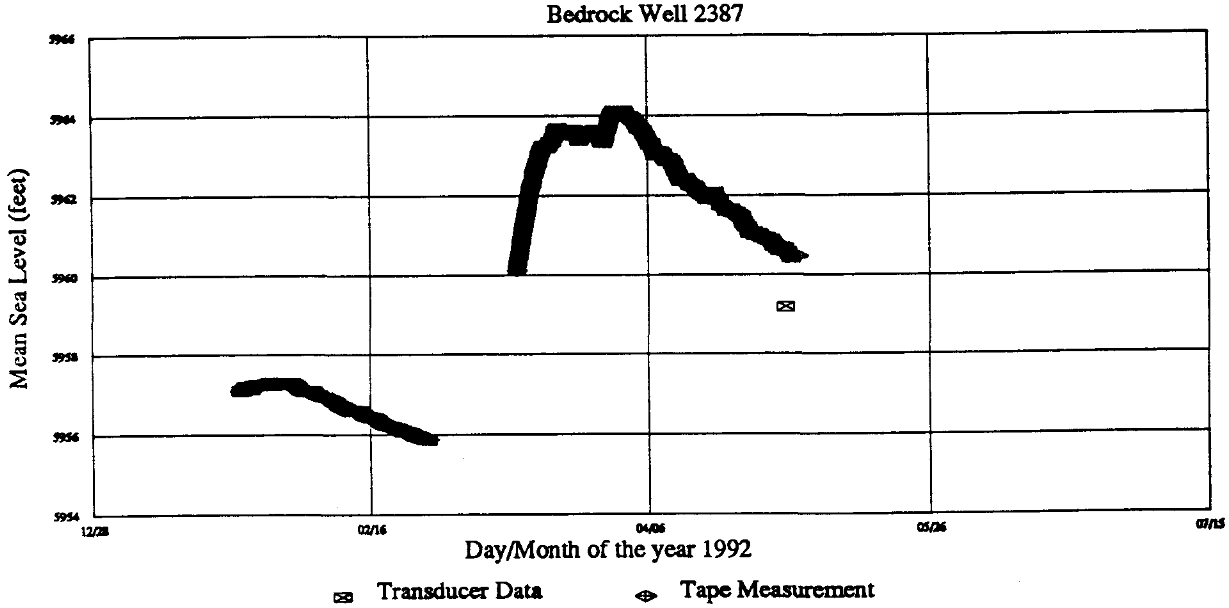
Hydrographs

Alluvial Well 4386



Open Interval 5969.91'-5956.11'

Bedrock Well 2387



Open Interval 5956.54'-5934.94'

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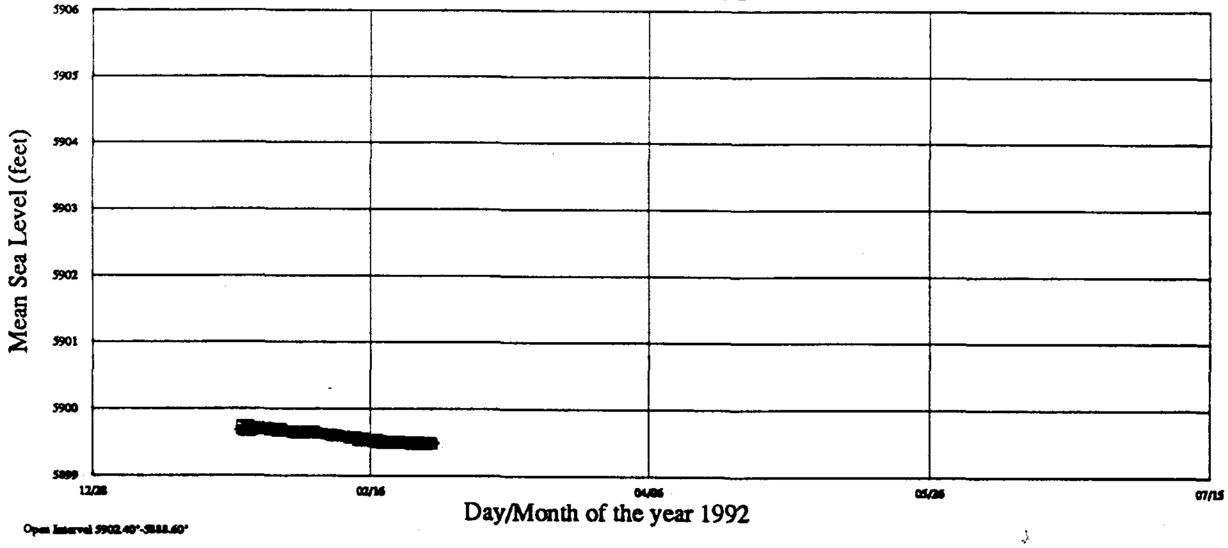
OPERABLE UNIT NO. 2
PHASE II RFI/RI AQUIFER TEST
REPORT

Hydrographs of 4386 and 2387
Background Water Level Trends

FIGURE 7 NOVEMBER, 1992

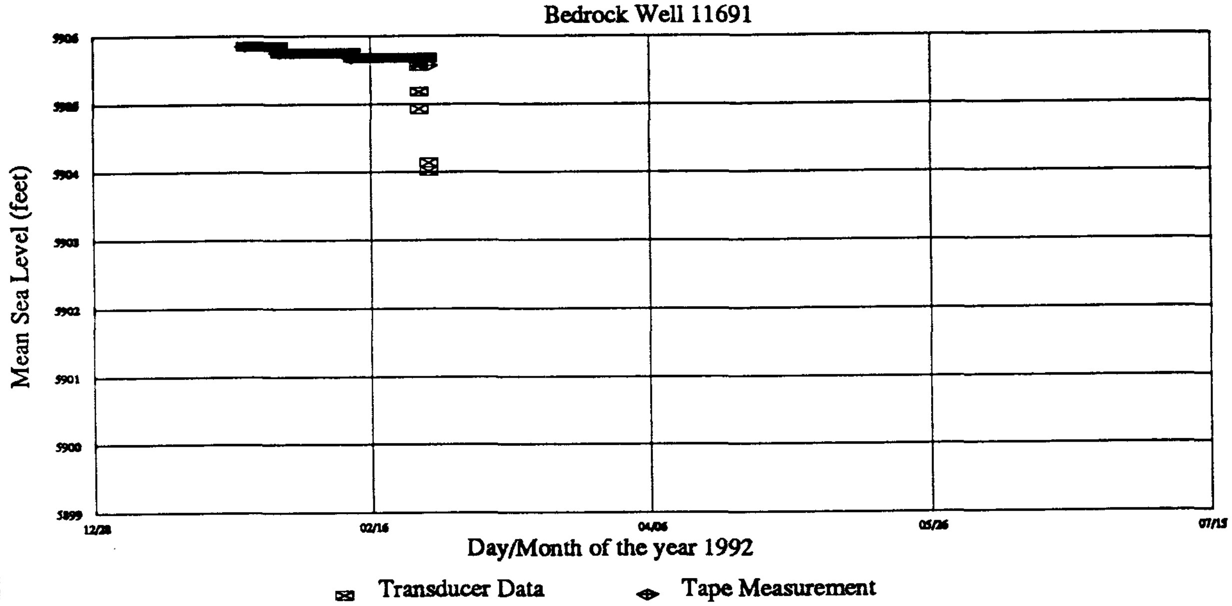
Hydrographs

Bedrock Well 3791



Open Interval 5902.40'-5888.60'

Bedrock Well 11691



Open Interval 5925.83'-5905.13'

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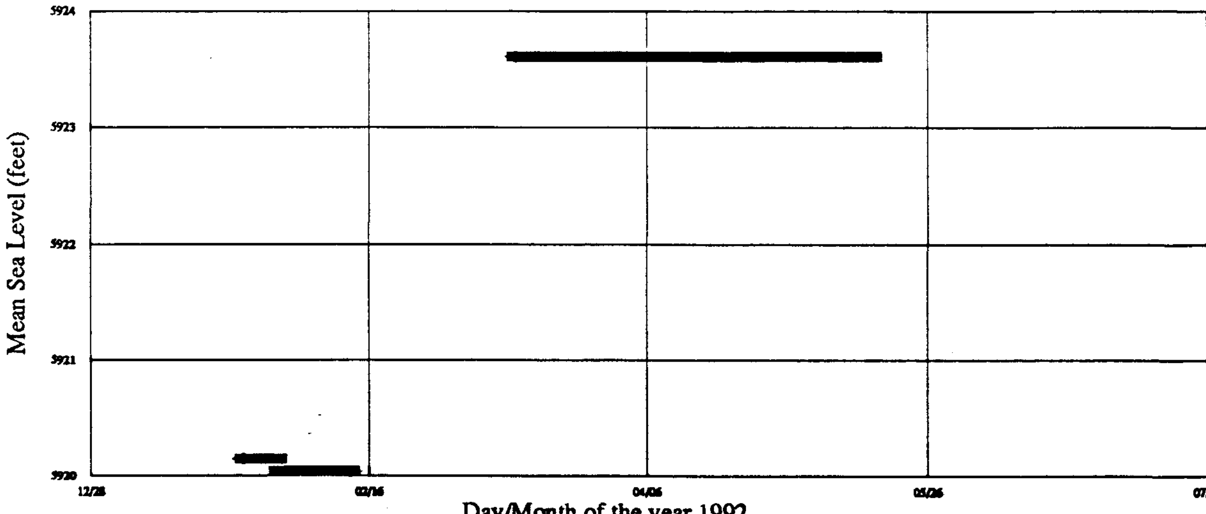
REPORT

Hydrographs of 3791 and 11691
Background Water Level Trends

FIGURE 8 NOVEMBER, 1992

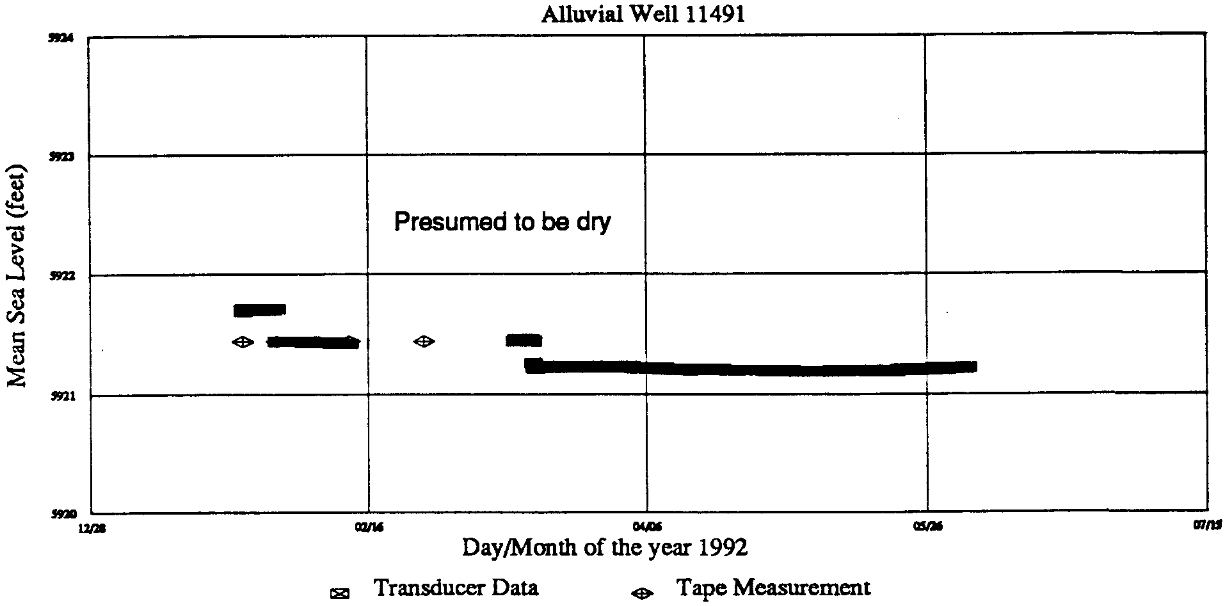
Hydrographs

Alluvial Well 5691



Open Interval 5924.61'-5910.51'

Alluvial Well 11491



Open Interval 5940.22'-5922.92'

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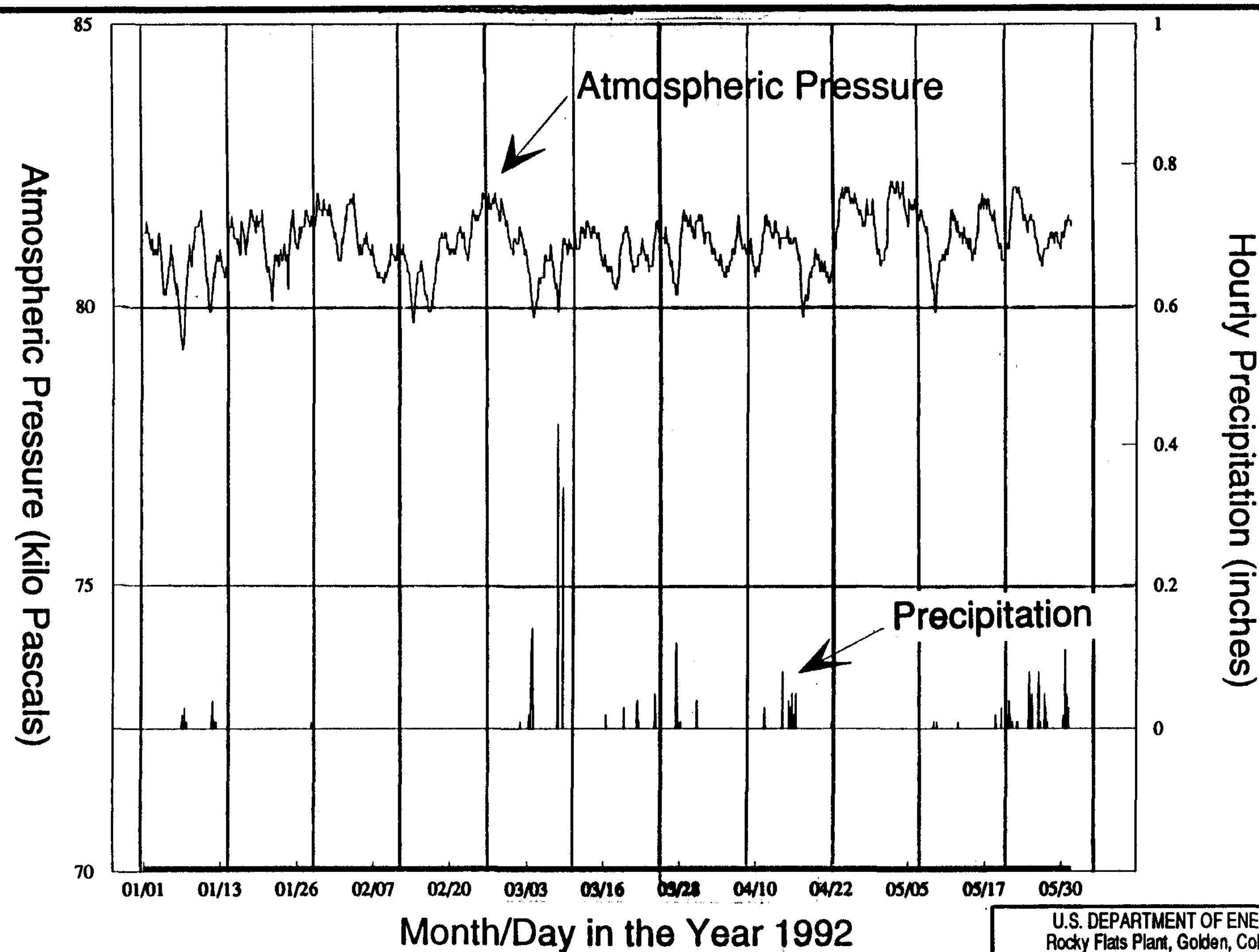
Hydrographs of 5691 and 11491
Background Water Level Trends

FIGURE 9 — NOVEMBER, 1992



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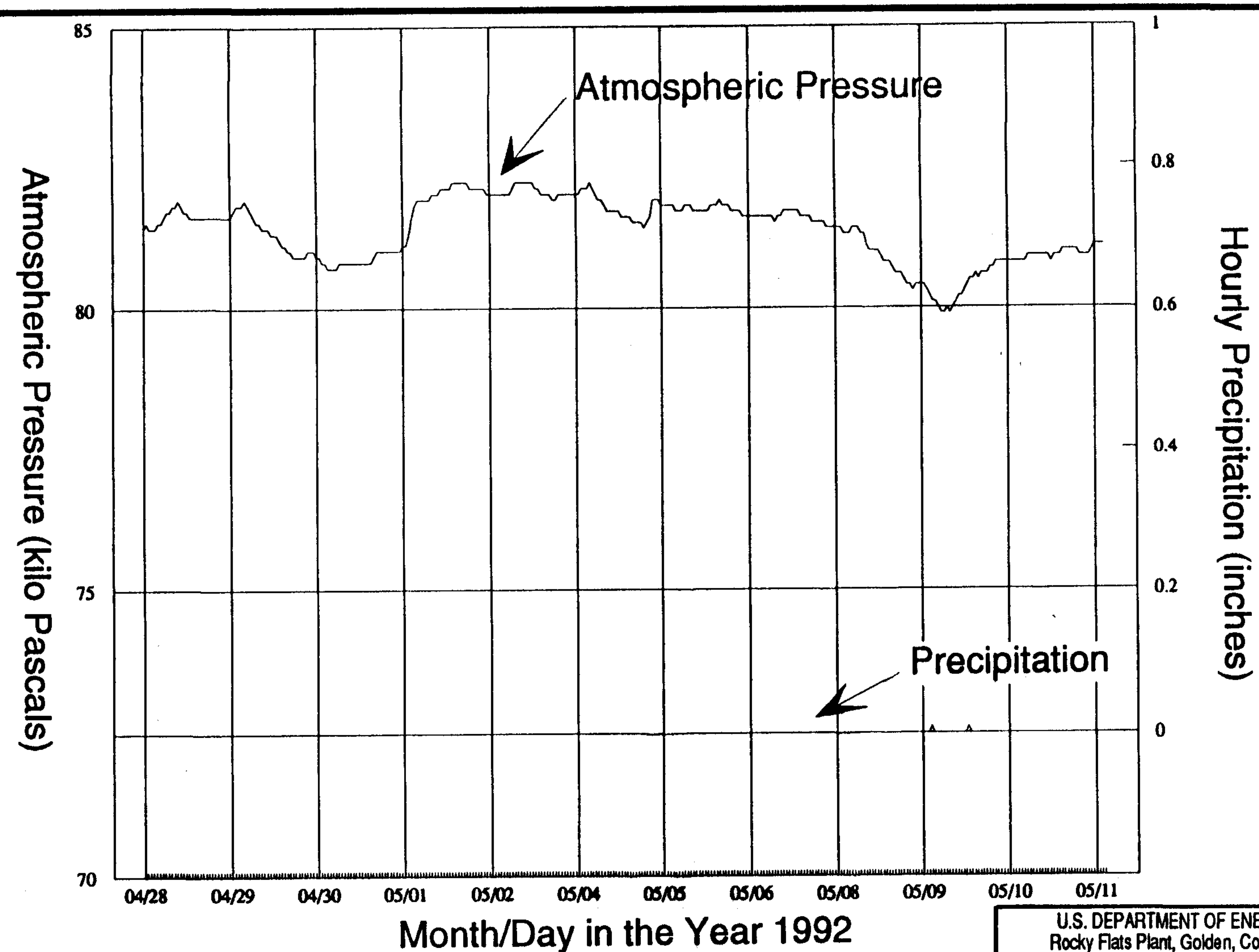
PHASE II RFI/RI AQUIFER TEST
REPORT

Barometric Pressure and Precipitation at RFP

FIGURE 10 November, 1992



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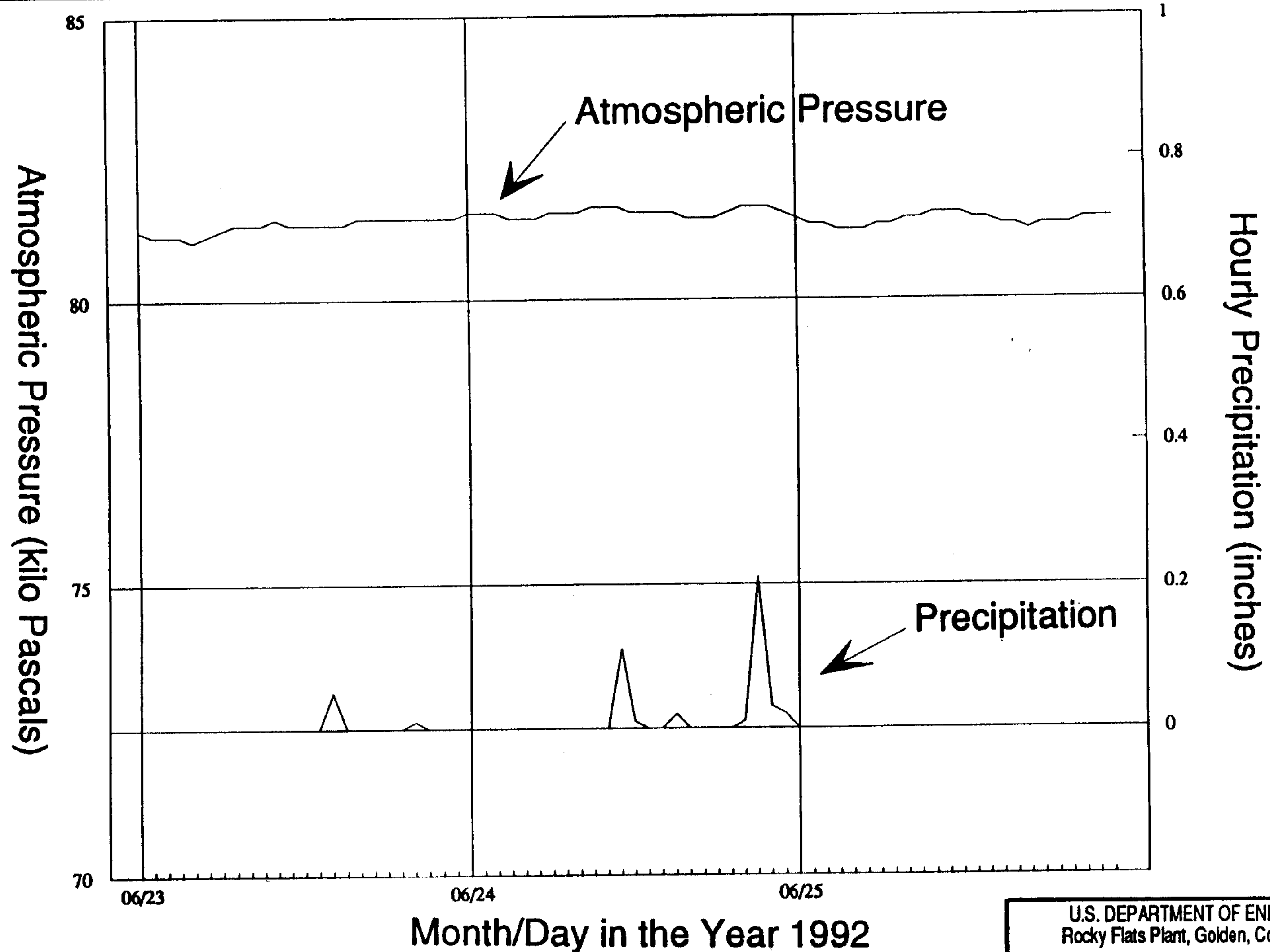
REPORT

Barometric Pressure and Precipitation
During Drawdown Phase
Site 1

FIGURE 11 NOVEMBER, 1992



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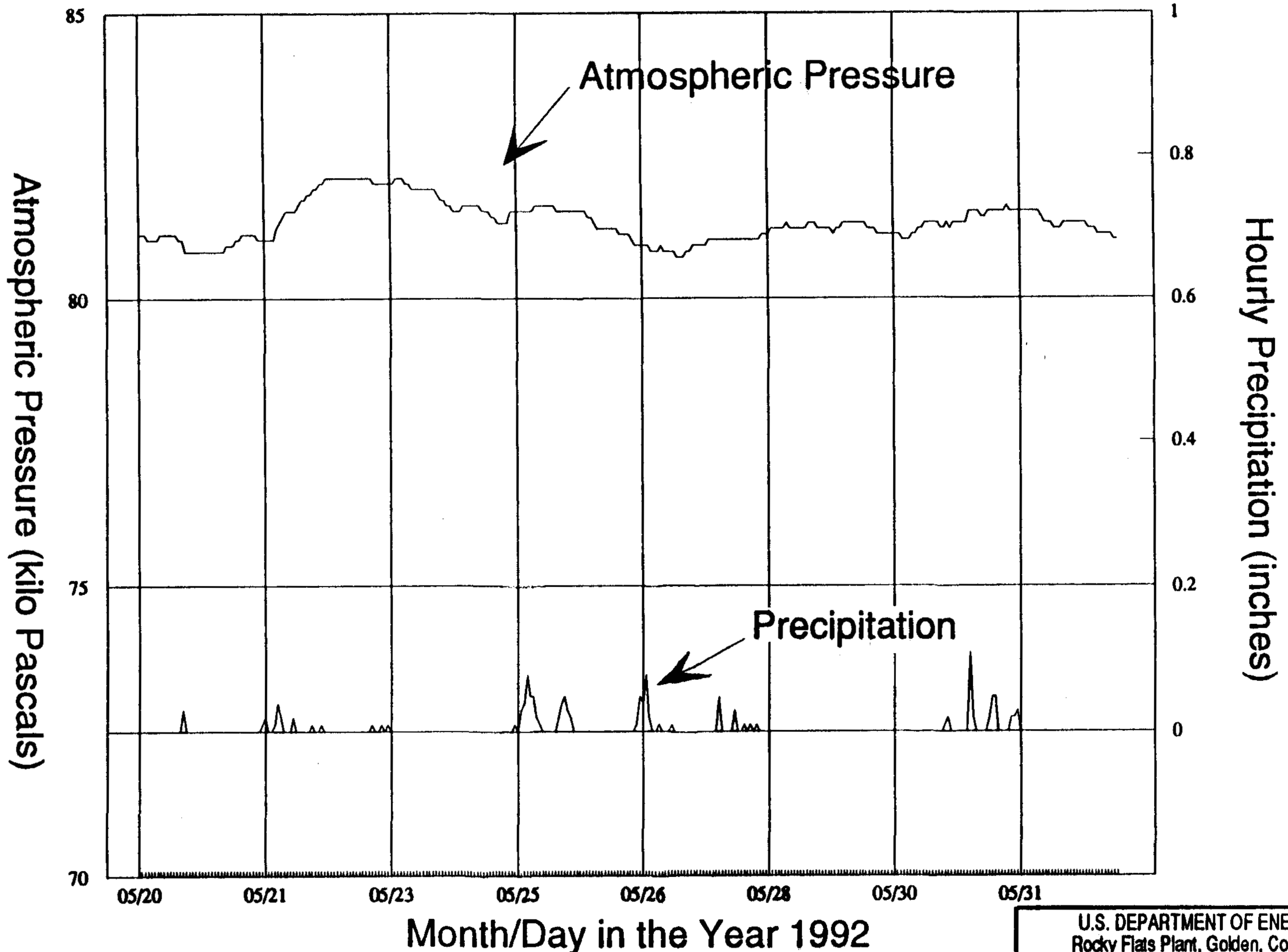
OPERABLE UNIT NO. 2
PHASE II RFI/RI AQUIFER TEST
REPORT
Barometric Pressure and Precipitation
During Drawdown Phase
Site 2

FIGURE 12 NOVEMBER, 1992



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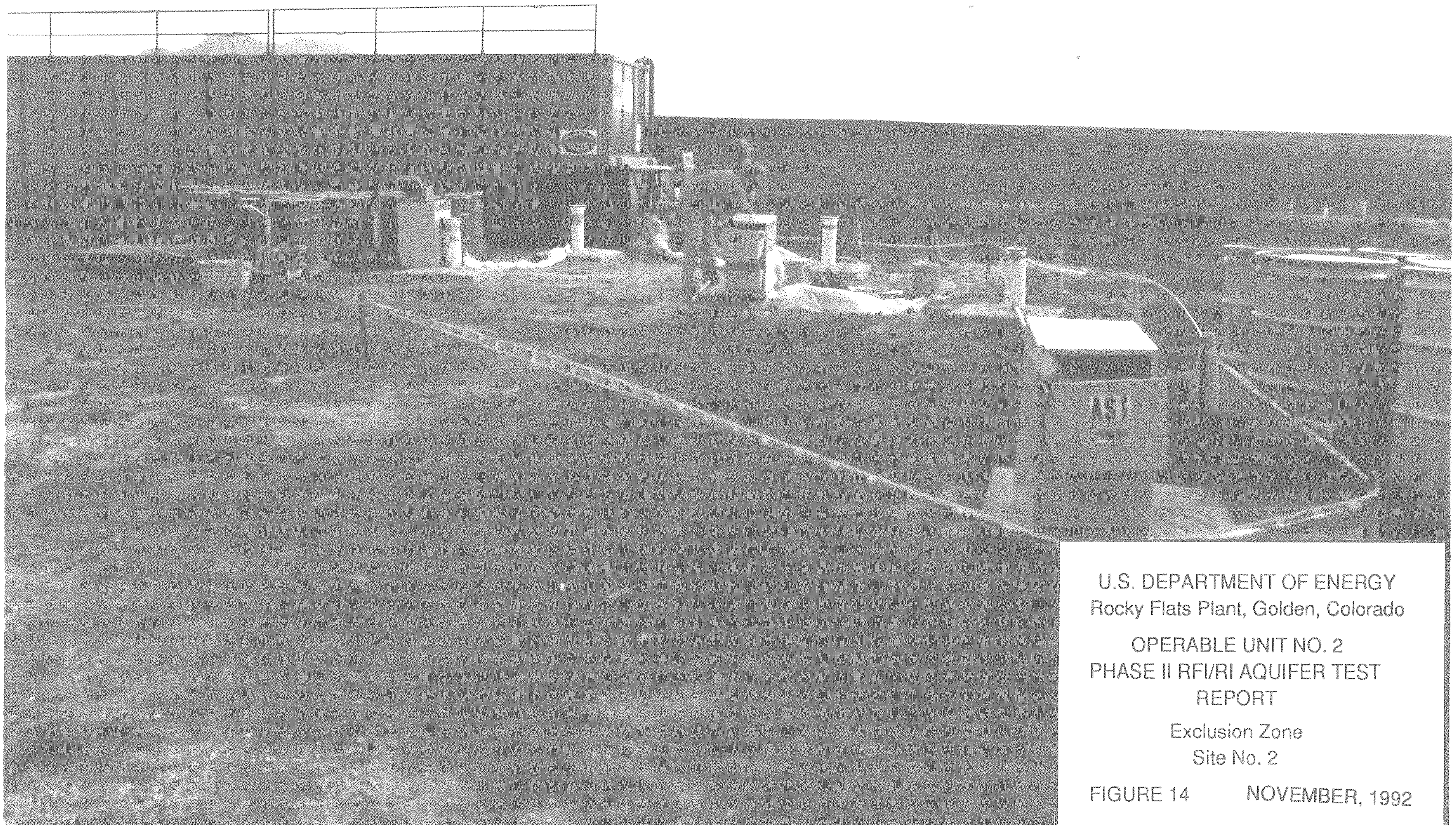
OPERABLE UNIT NO. 2
PHASE II RFI/RI AQUIFER TEST
REPORT
Barometric Pressure and Precipitation
During Drawdown Phase
Site 3

FIGURE 13 NOVEMBER, 1992



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OPERABLE UNIT NO. 2
PHASE II RFI/RI AQUIFER TEST
REPORT

Exclusion Zone
Site No. 2

FIGURE 14 NOVEMBER, 1992

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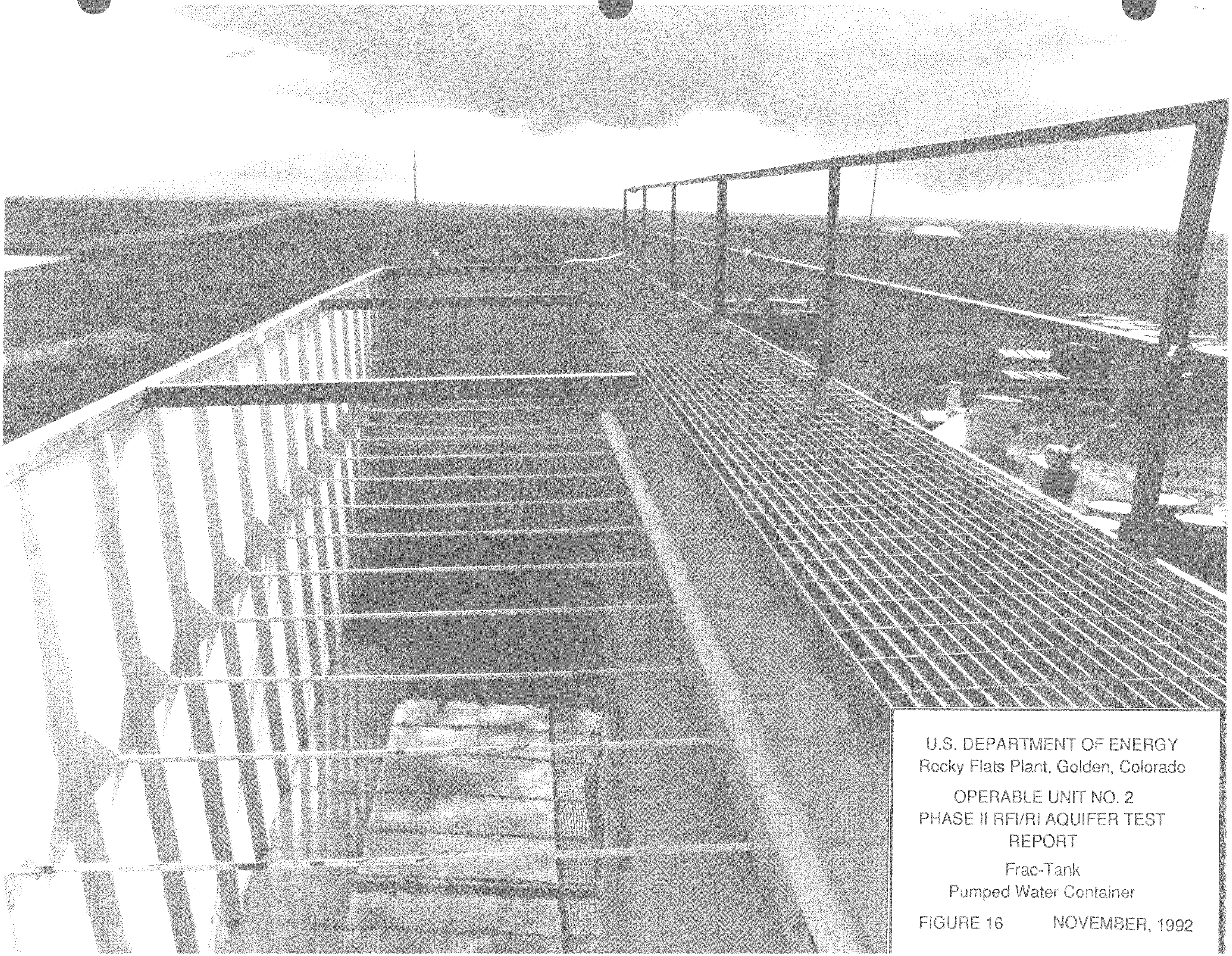
Rocky Flats Plant, Golden, Colorado

OPERABLE UNIT NO. 2
PHASE II RFI/RI AQUIFER TEST
REPORT

Diesel Generator
Power Source

FIGURE 15 NOVEMBER, 1992



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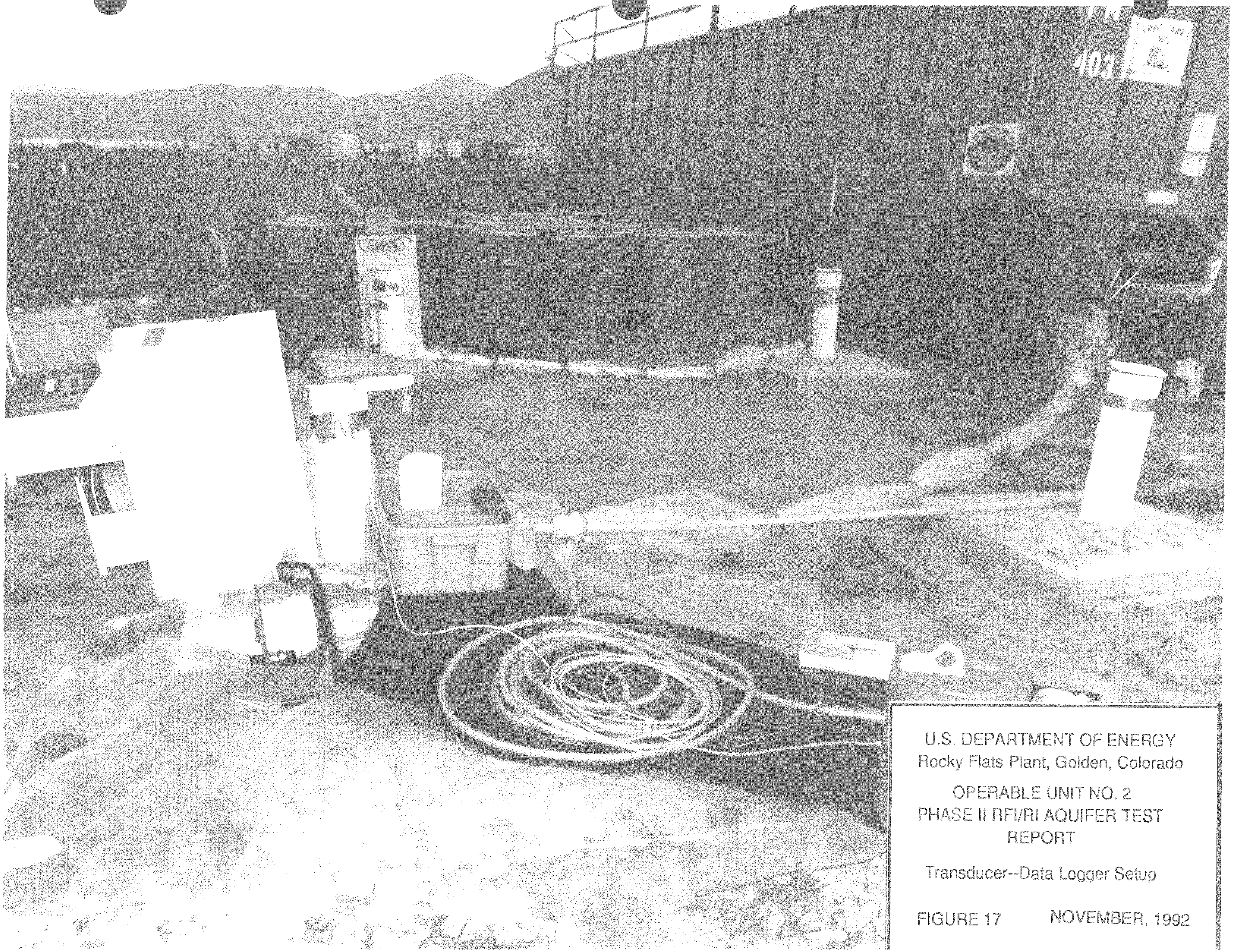
Rocky Flats Plant, Golden, Colorado

OPERABLE UNIT NO. 2
PHASE II RFI/RI AQUIFER TEST
REPORT

Frac-Tank
Pumped Water Container

FIGURE 16 NOVEMBER, 1992



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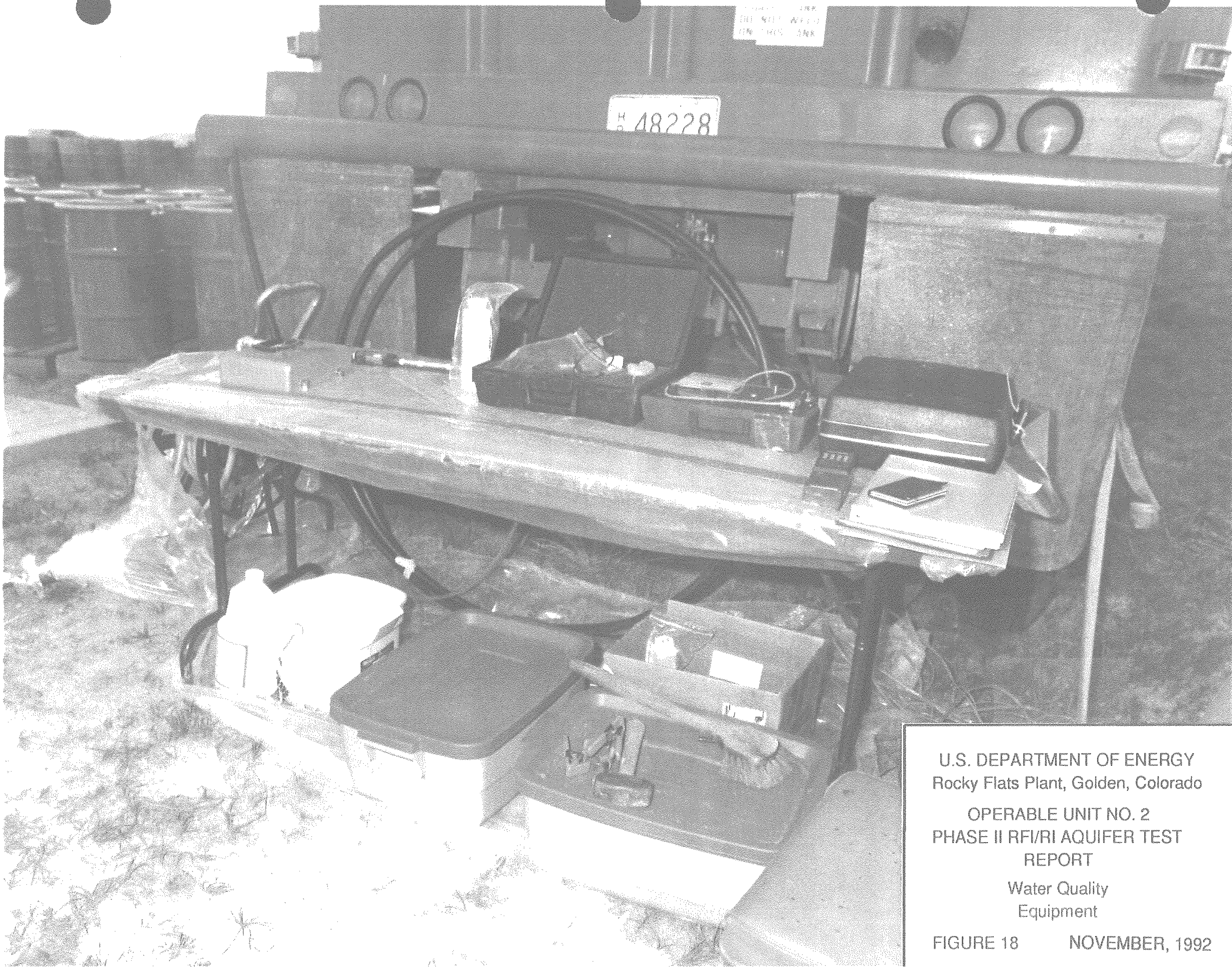
OPERABLE UNIT NO. 2
PHASE II RFI/RI AQUIFER TEST
REPORT

Transducer--Data Logger Setup

FIGURE 17 NOVEMBER, 1992



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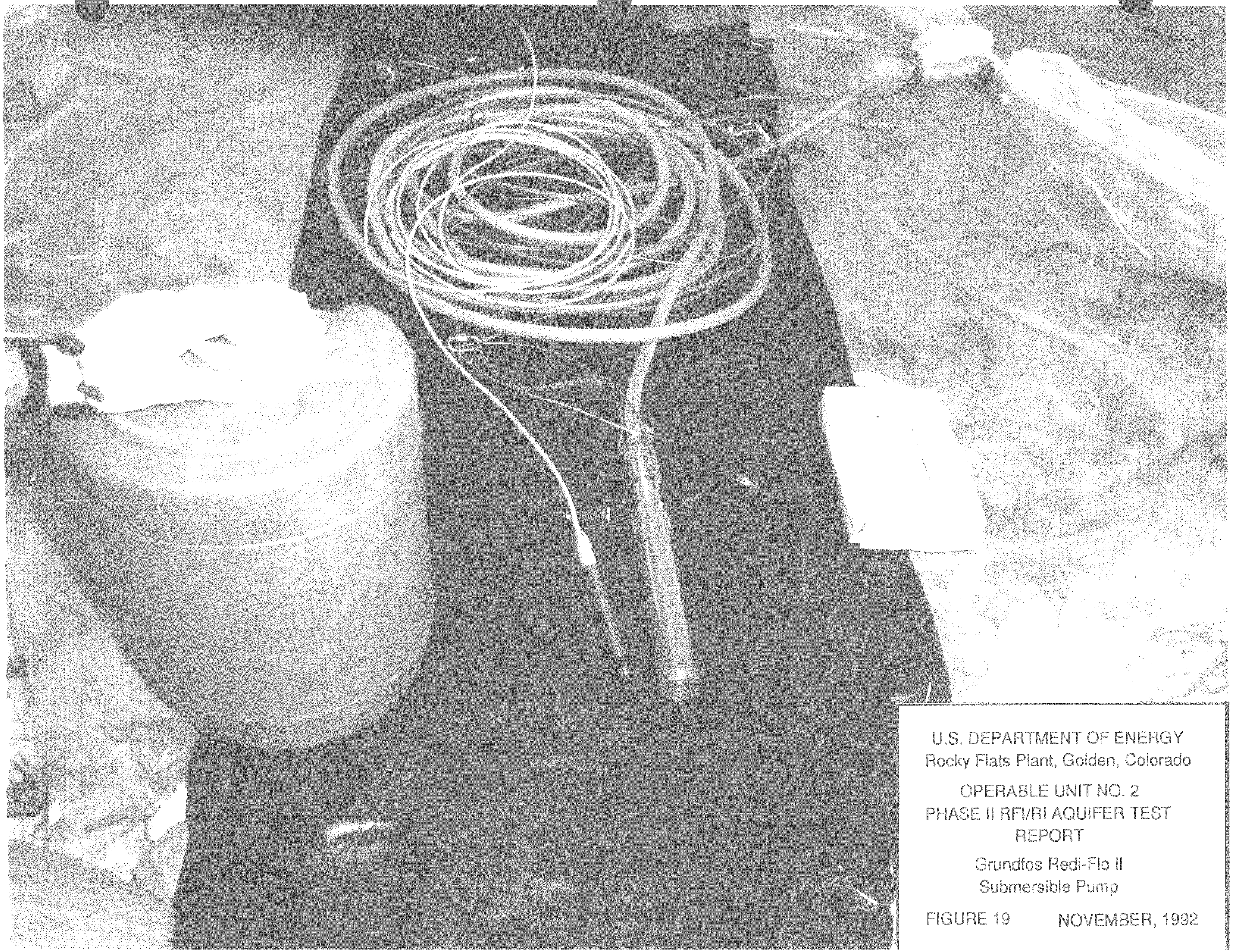
OPERABLE UNIT NO. 2
PHASE II RFI/RI AQUIFER TEST
REPORT

Water Quality
Equipment

FIGURE 18 NOVEMBER, 1992



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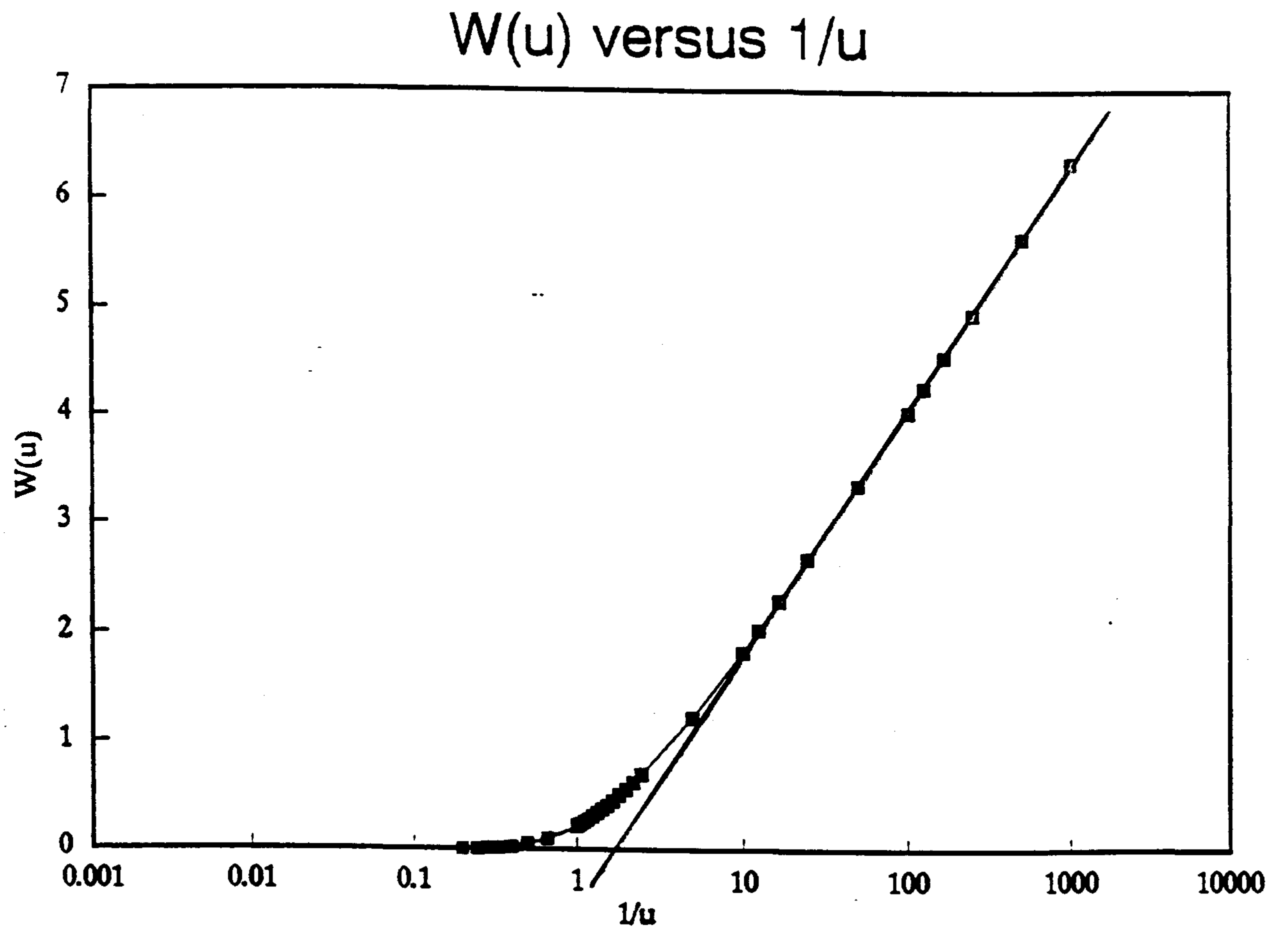
Rocky Flats Plant, Golden, Colorado

OPERABLE UNIT NO. 2
PHASE II RFI/RI AQUIFER TEST
REPORT

Grundfos Redi-Flo II
Submersible Pump

FIGURE 19 NOVEMBER, 1992



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PHASE II RFI/RI AQUIFER TEST
REPORT

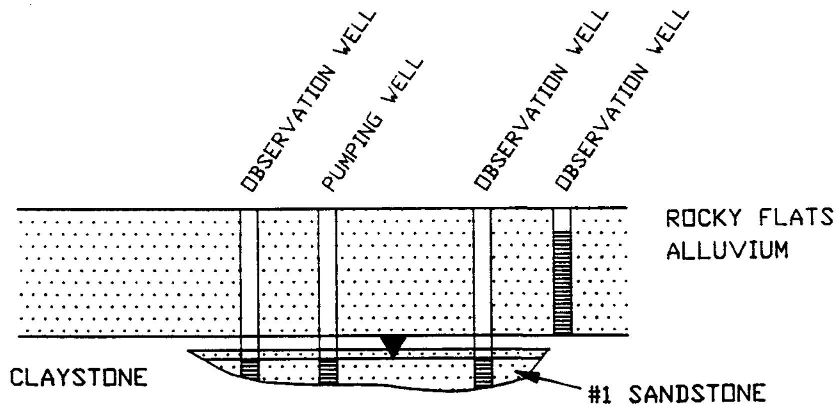
W(u) vs. 1/u

FIGURE 20 NOVEMBER, 1992

SITE No. 1

ALLUVIUM DRY
SATURATED SANDSTONE

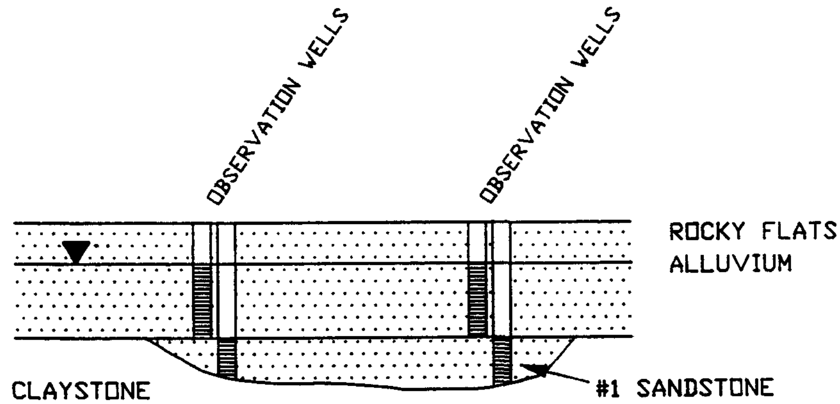
MULTI-WELL PUMPING TEST



SITE No. 2

SATURATED ALLUVIUM &
SATURATED SANDSTONE

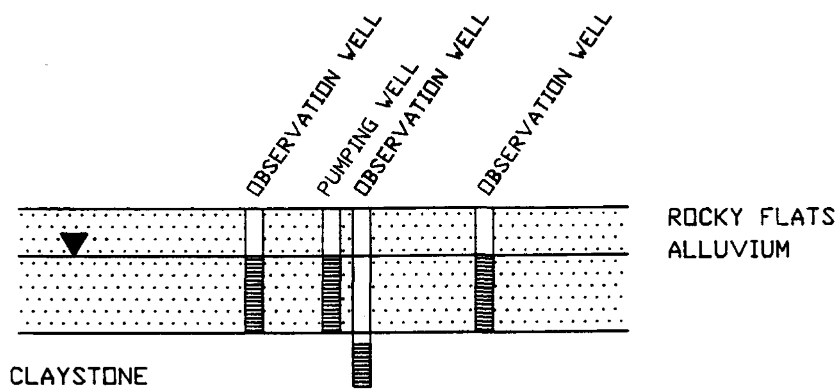
PUMPING TEST OF ALLUVIUM
WITH PAIRED OBSERVATION
WELLS IN ALLUVIUM AND SANDSTONE



SITE No. 3

SATURATED ALLUVIUM
UNDERLAIN BY CLAYSTONE

PUMPING TEST OF ALLUVIUM WITH
OBSERVATION WELL IN CLAYSTONE



NOTE: NOT TO SCALE

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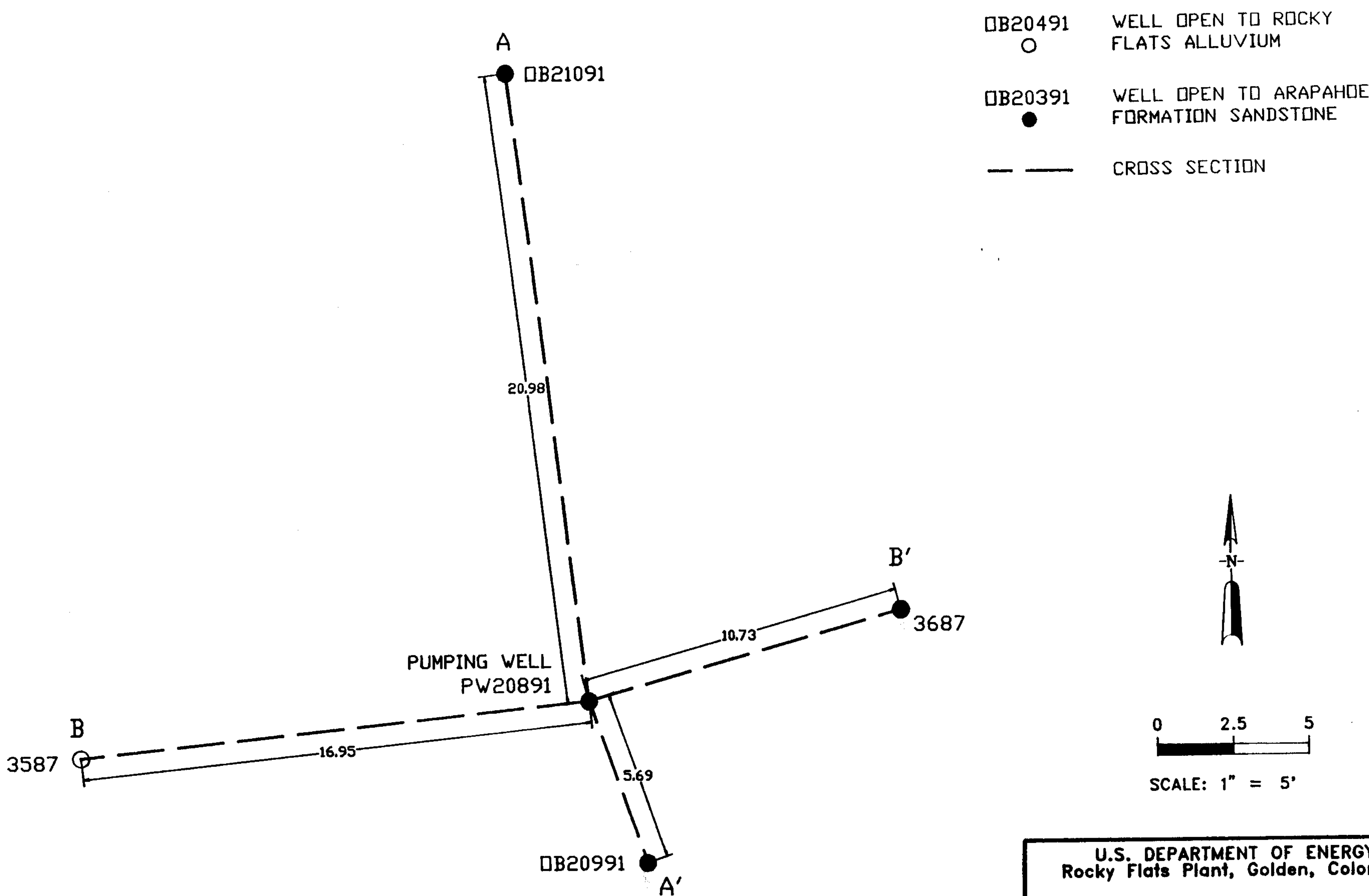
TEST REPORT

TEST DESIGN DIAGRAMS

FIGURE 21

November, 1992



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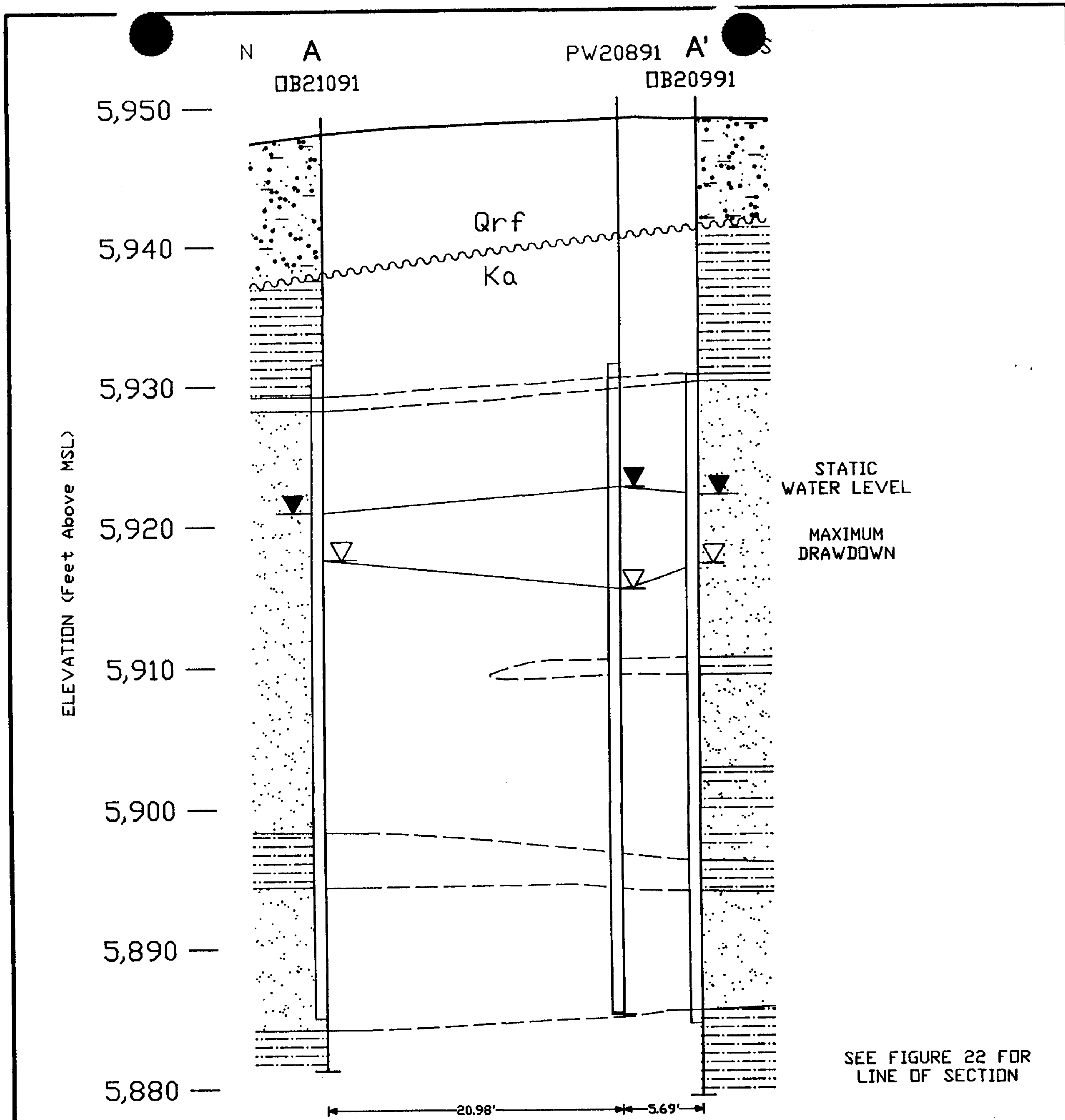
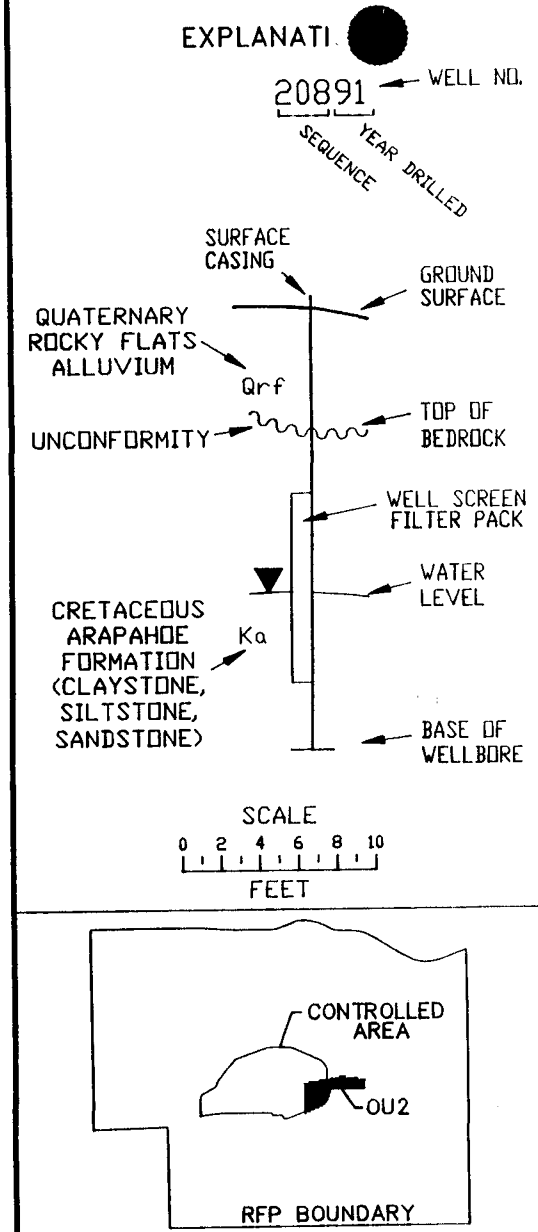
TEST REPORT

SITE No. 1 WELL FIELD

FIGURE 22

November, 1992





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OPERABLE UNIT NO. 2
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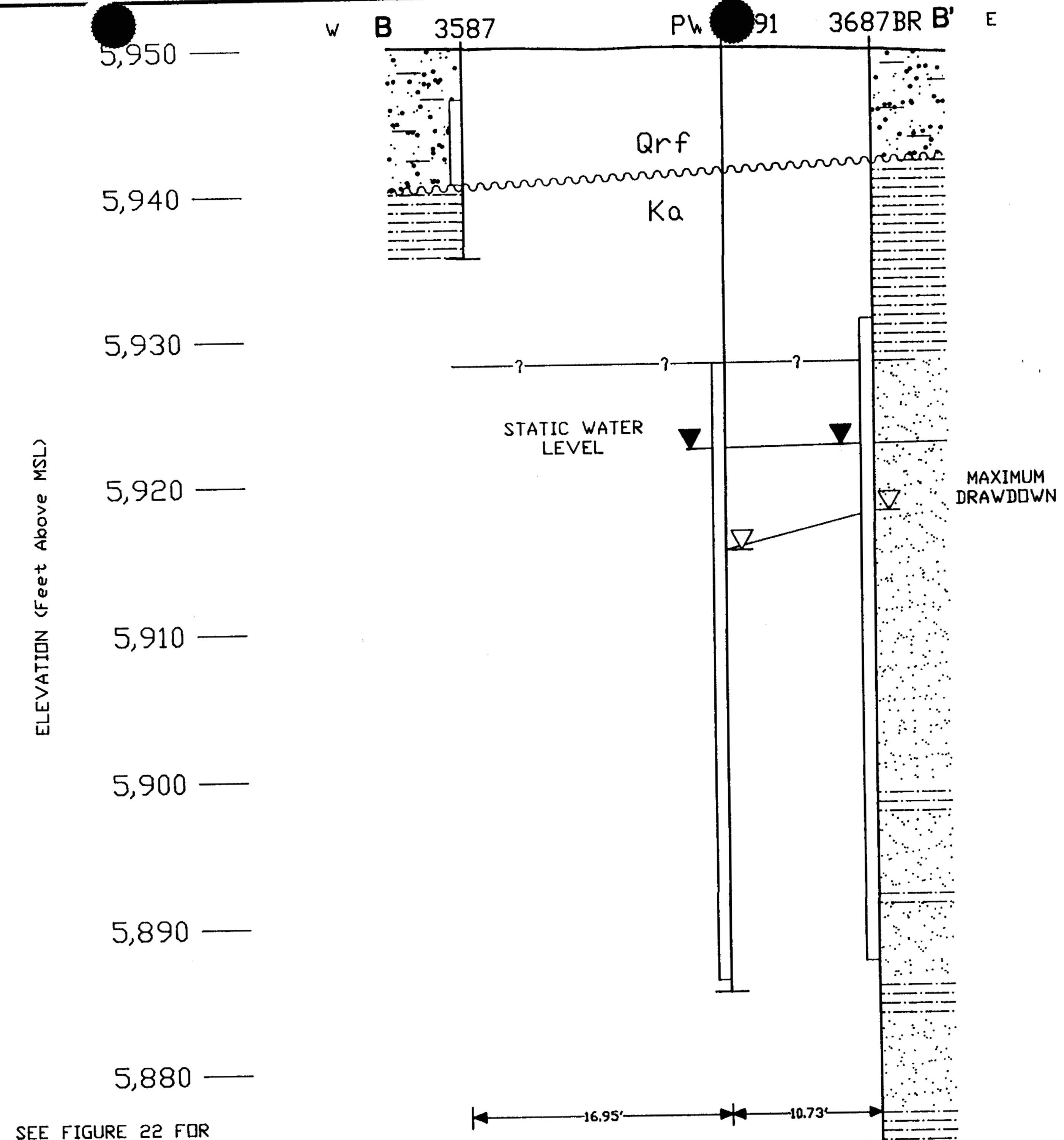
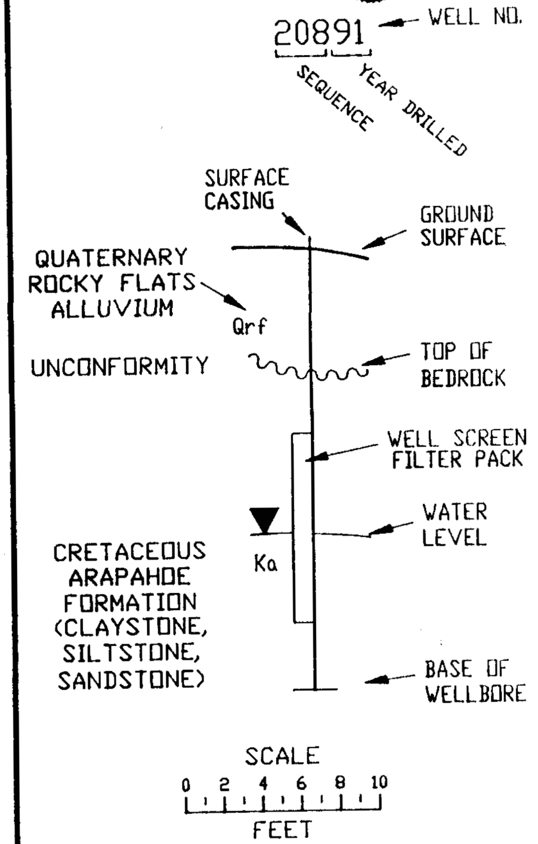
GEOLOGIC CROSS SECTION A – A'
SITE No. 1

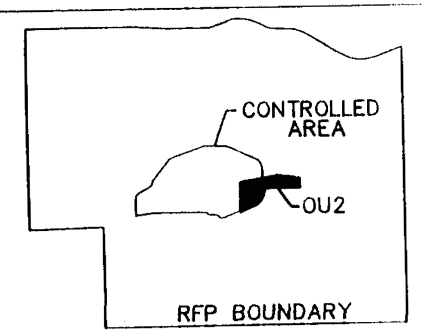
FIGURE 23

November, 1992



EXPLANATI





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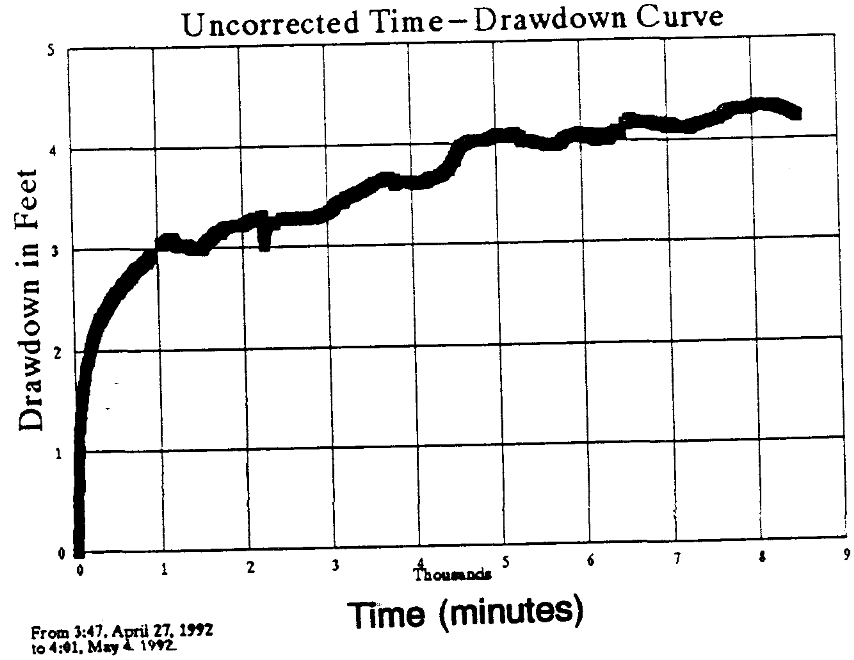
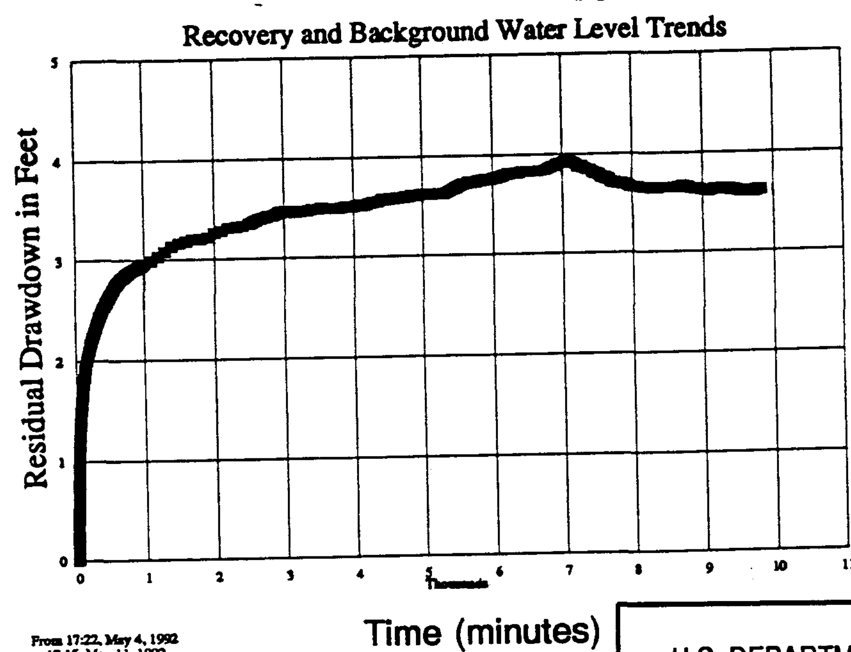
GEOLOGIC CROSS SECTION B – B'
SITE No. 1

FIGURE 24
November, 1992

Bedrock Well 3687-Site 1





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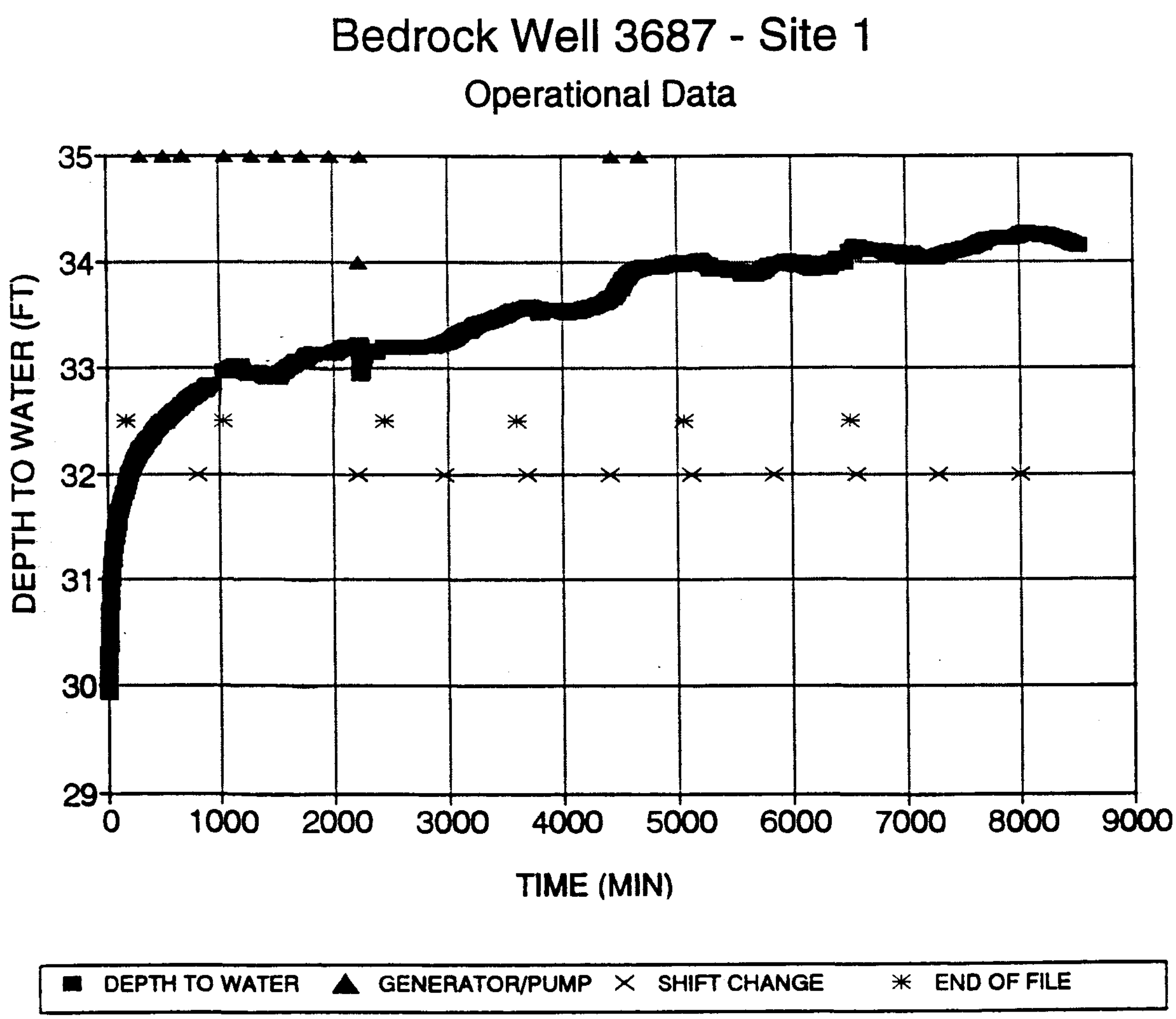
Drawdown, Recovery and Background Water Level Trends for 3687

FIGURE 25 **NOVEMBER, 1992**



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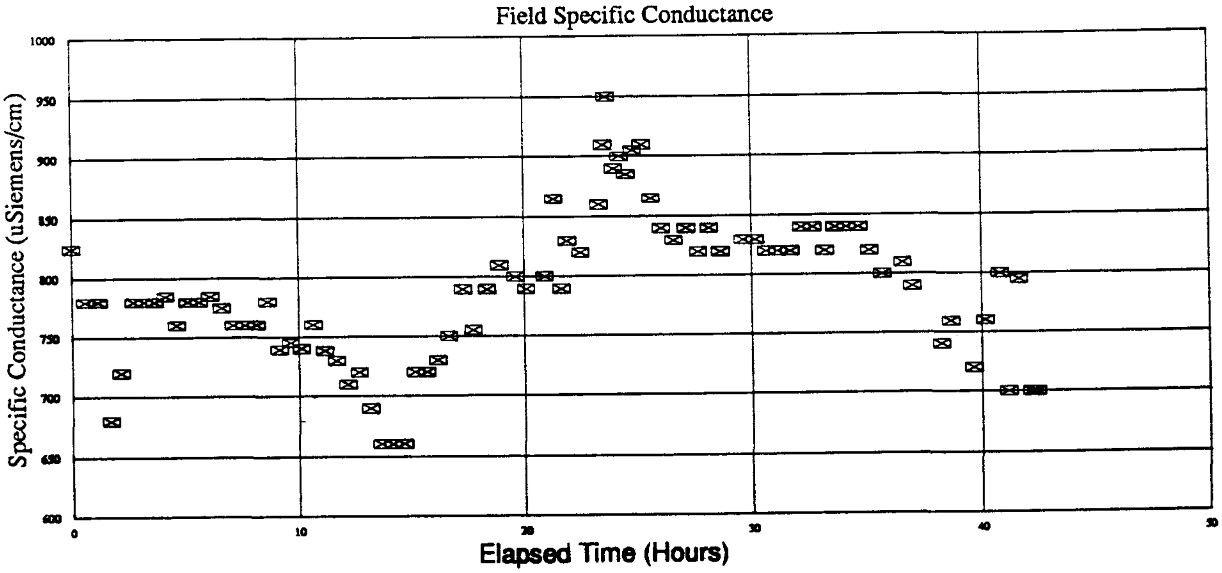
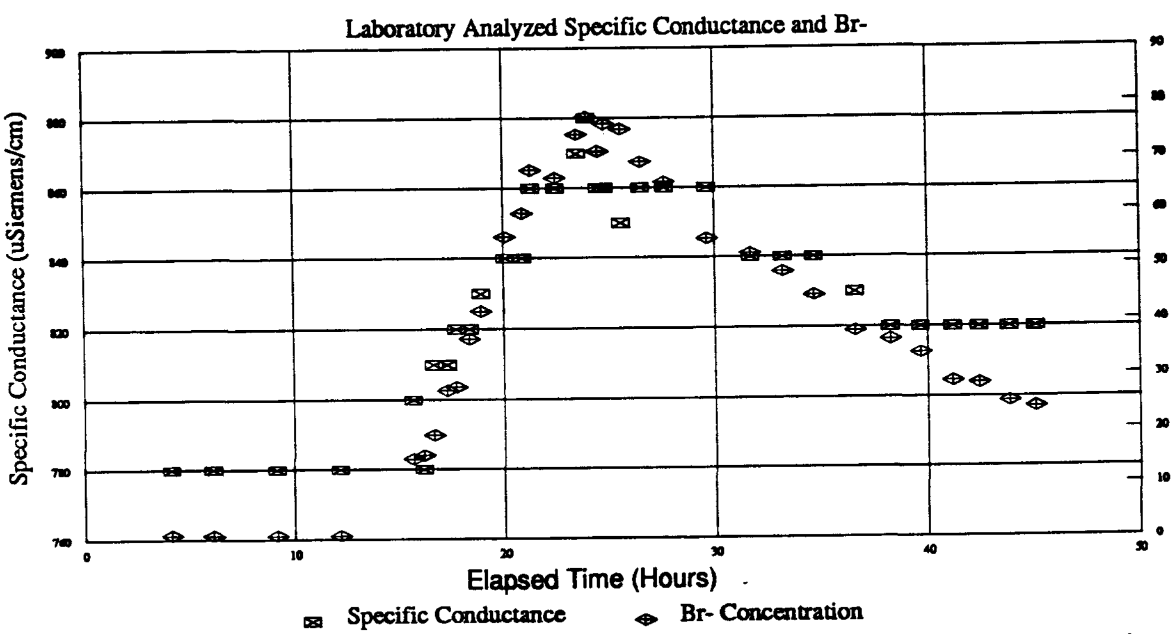
Operational Data
3687 Hydrograph

FIGURE 26 NOVEMBER, 1992

Site 1 Tracer Test Data





U.S. DEPARTMENT OF ENERGY
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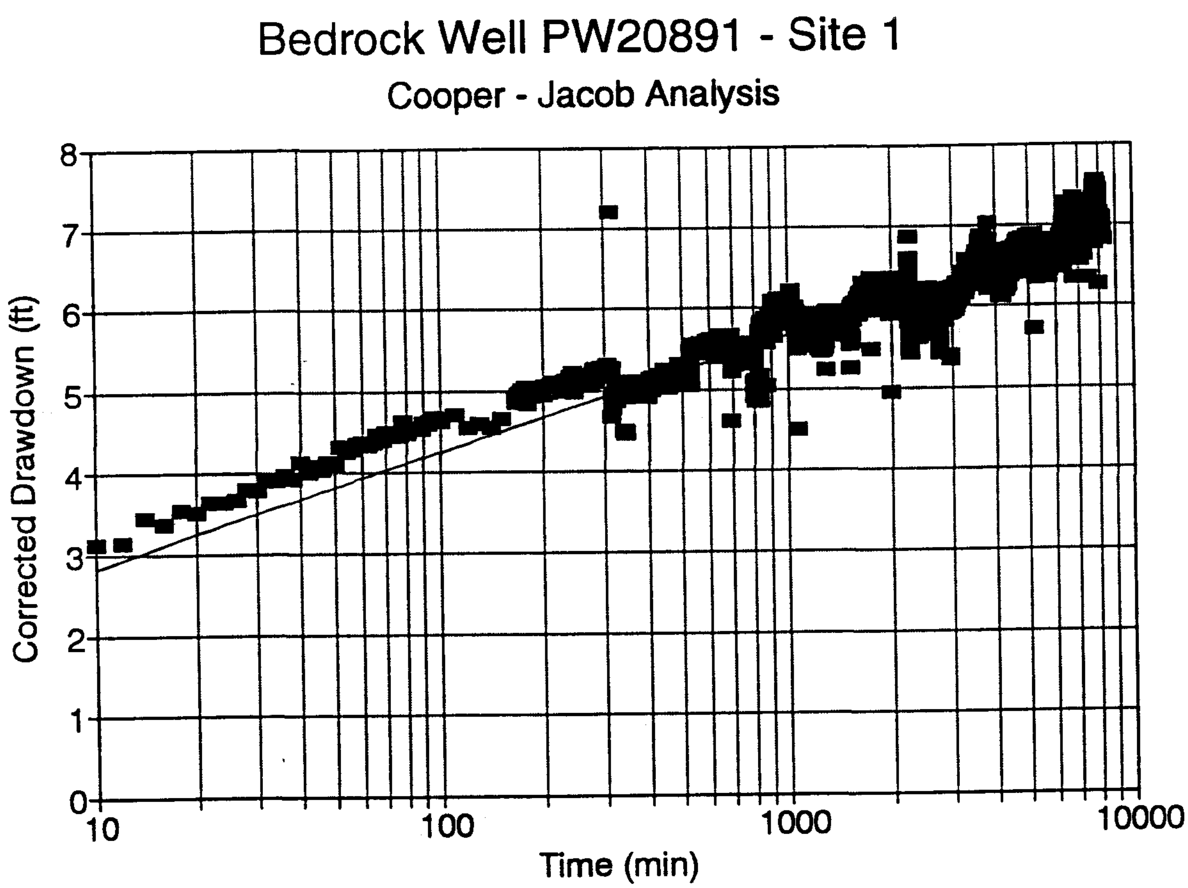
REPORT

Tracer Test Data
for Site 1

FIGURE 27 NOVEMBER, 1992



T = 0.02802 ft^2/min
S = 0.03606

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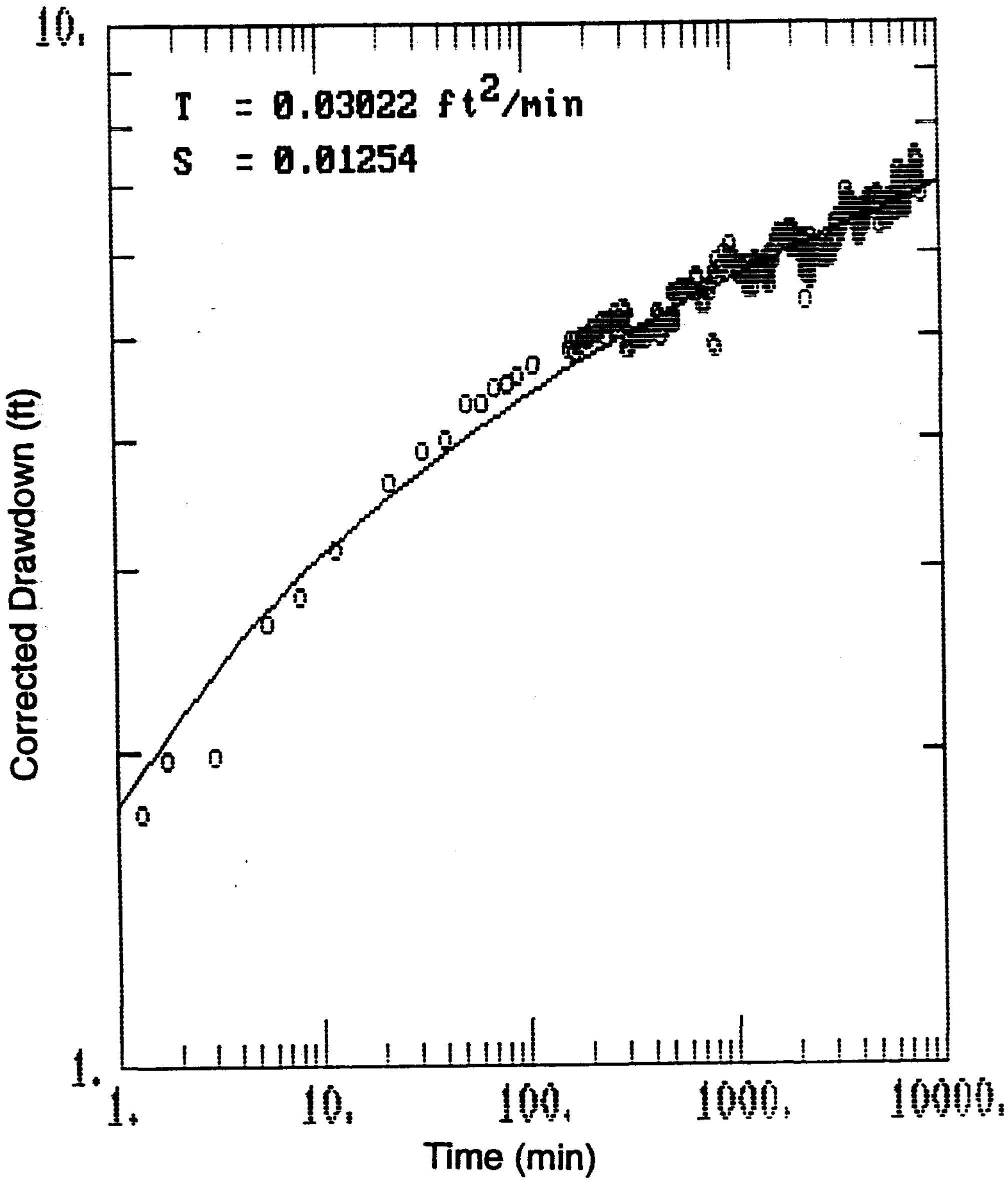
PHASE II RFI/RI AQUIFER TEST REPORT

PW20891
Cooper-Jacob Analysis

FIGURE 28 NOVEMBER, 1992

Bedrock Well PW20891 - Site 1

Theis Analysis



U.S. DEPARTMENT OF ENERGY
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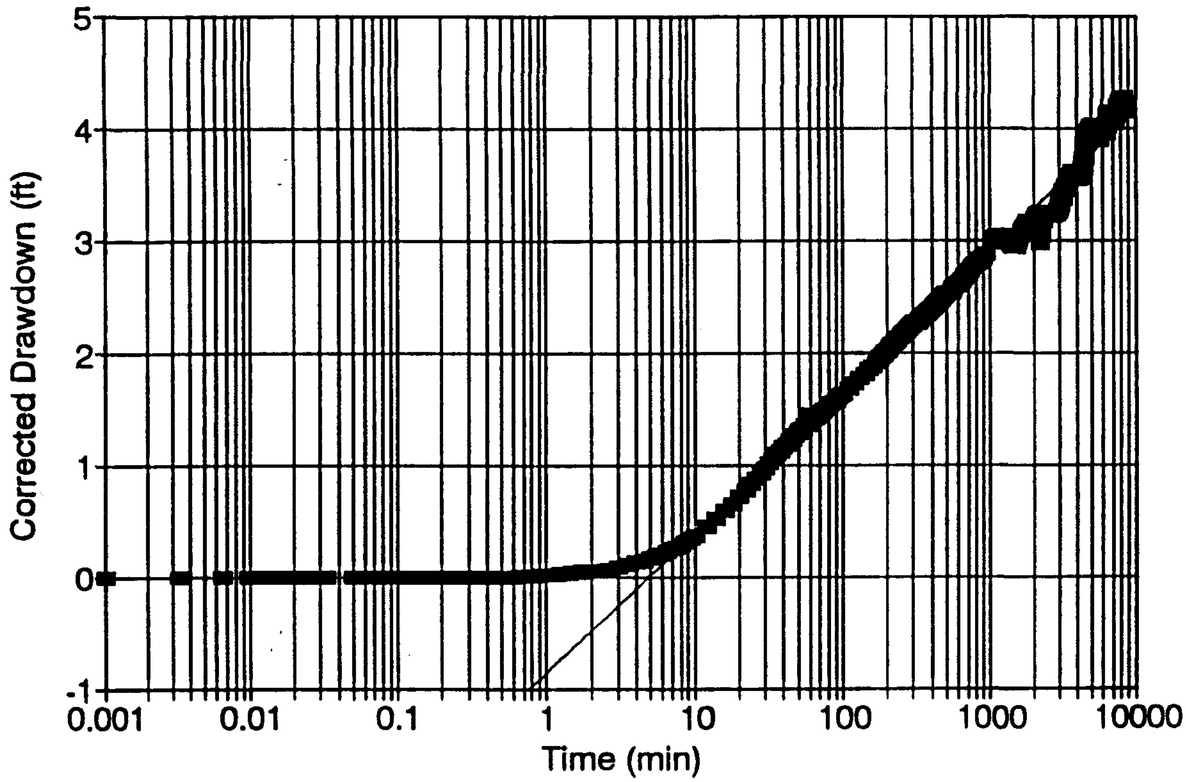
OPERABLE UNIT NO. 2
PHASE II RFI/RI AQUIFER TEST
REPORT

PW20891
Theis Analysis

FIGURE 29 **NOVEMBER, 1992**

Bedrock Well 3687 - Site 1

Cooper - Jacob Analysis



T = 0.03161 ft^2/min

S = 0.003014

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Rocky Flats Plant, Golden, Colorado

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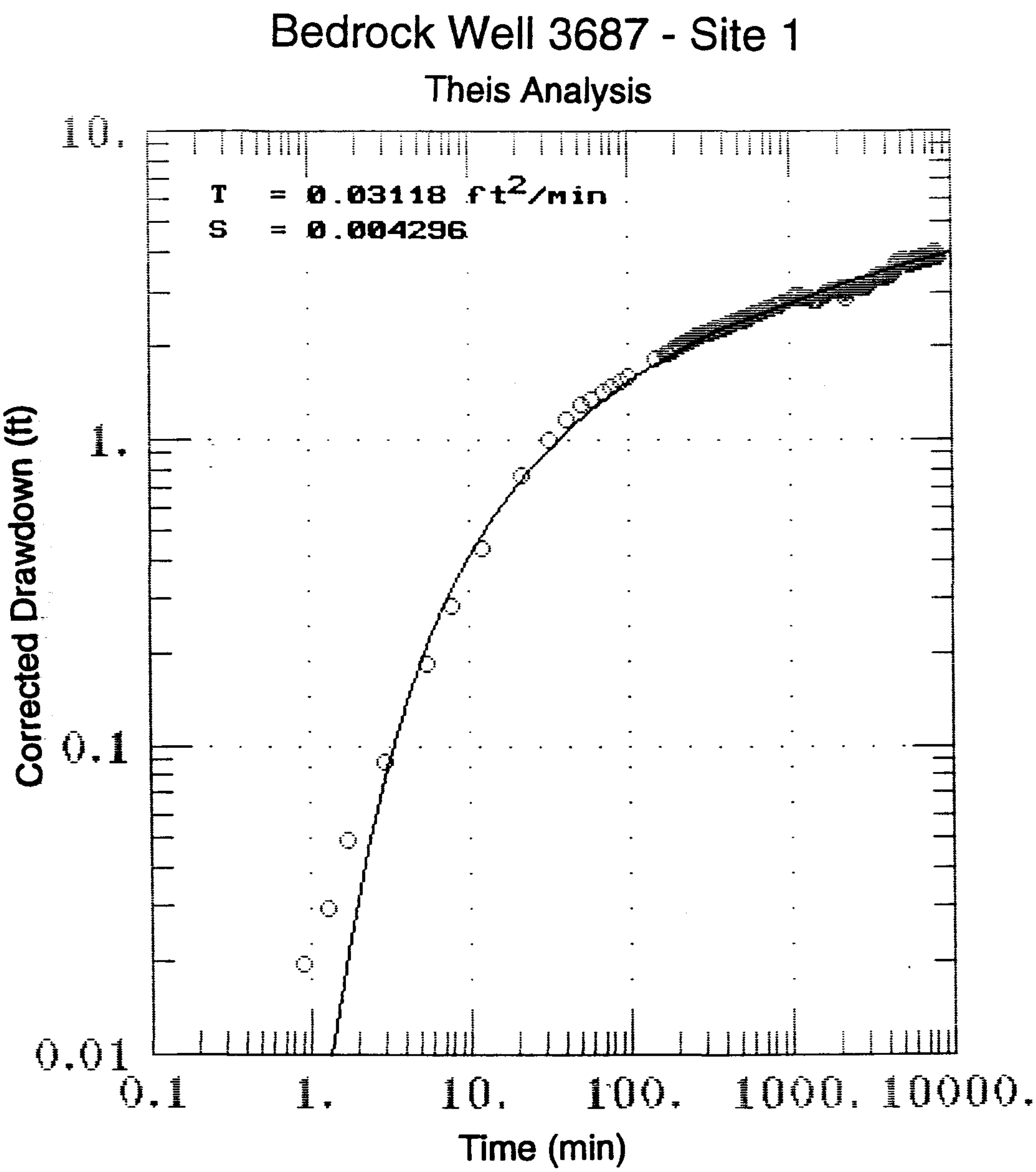
PHASE II RFI/RI AQUIFER TEST
REPORT

3687
Cooper-Jacob Analysis

FIGURE 30 NOVEMBER, 1992



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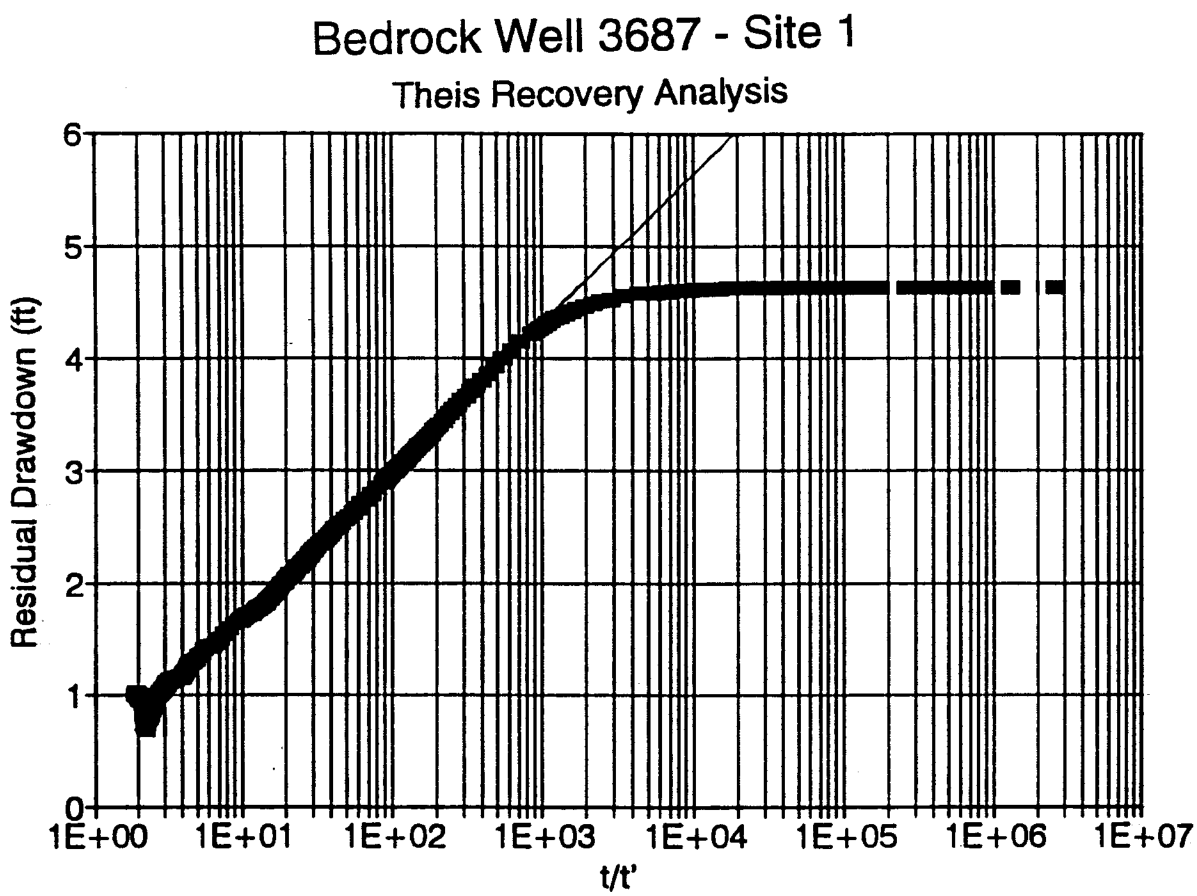
3687
Theis Analysis

FIGURE 31 NOVEMBER, 1992



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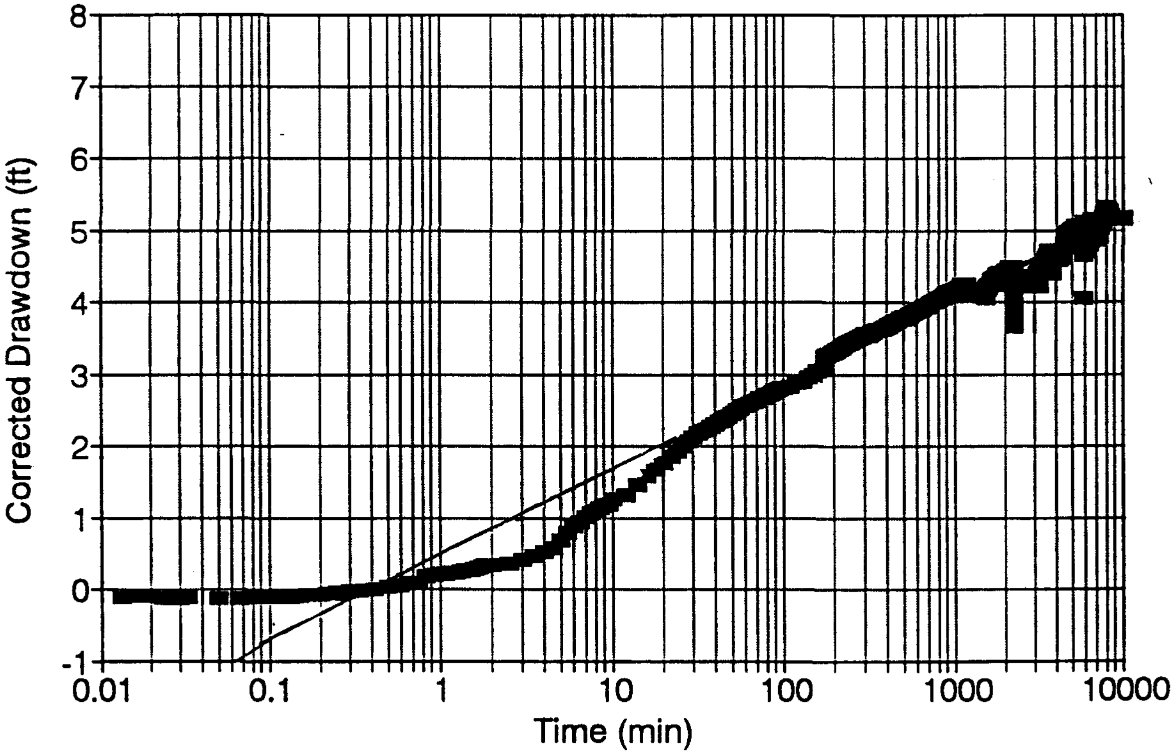
REPORT

3687
Theis Recovery Analysis

FIGURE 32 **NOVEMBER, 1992**

Bedrock Well OB20991 - Site 1

Cooper - Jacob Analysis



T = 0.03405 ft^2/min
S = 0.0008030

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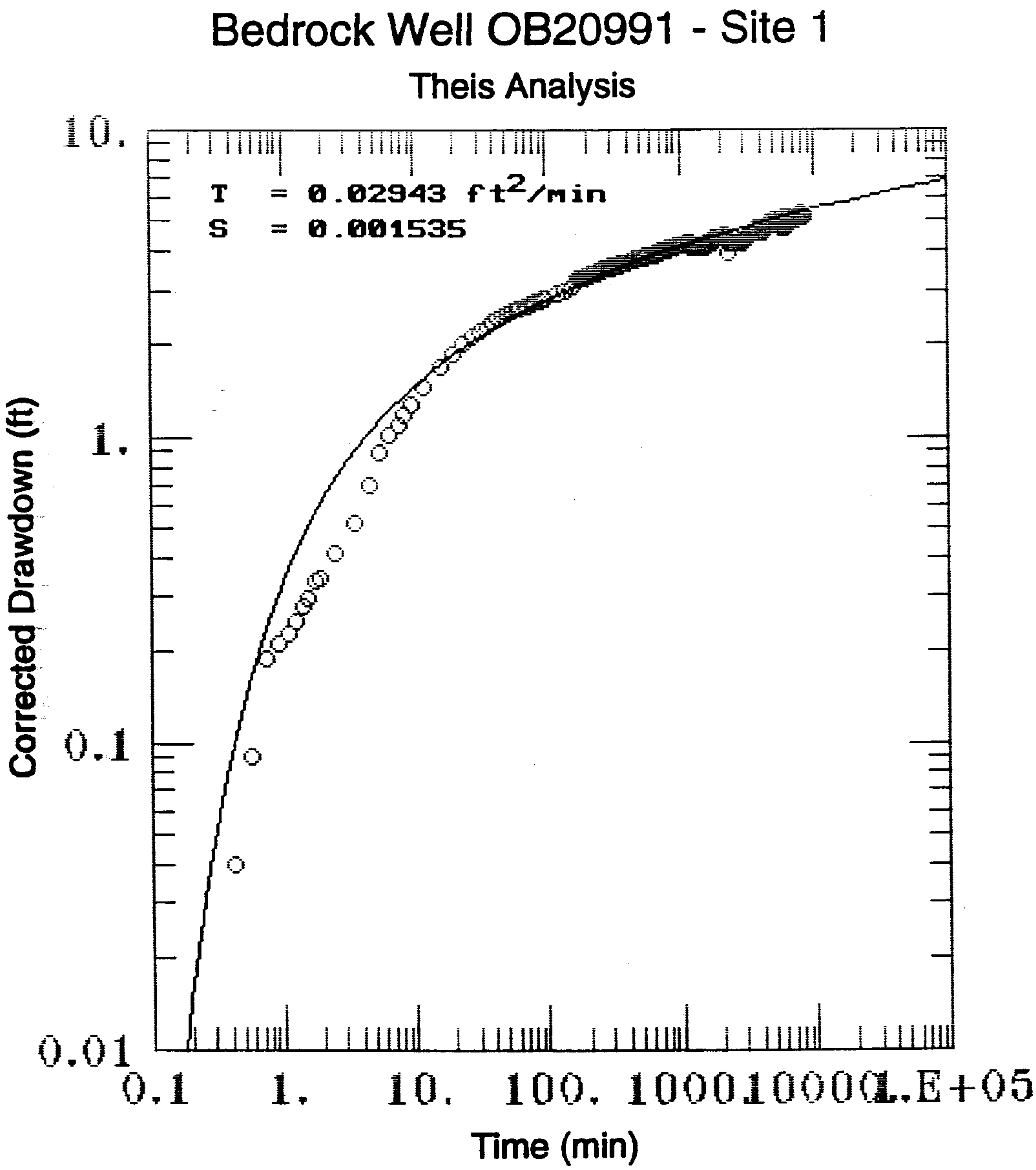
PHASE II RFI/RI AQUIFER TEST
REPORT

OB20991
Cooper-Jacob Analysis

FIGURE 33 NOVEMBER, 1992



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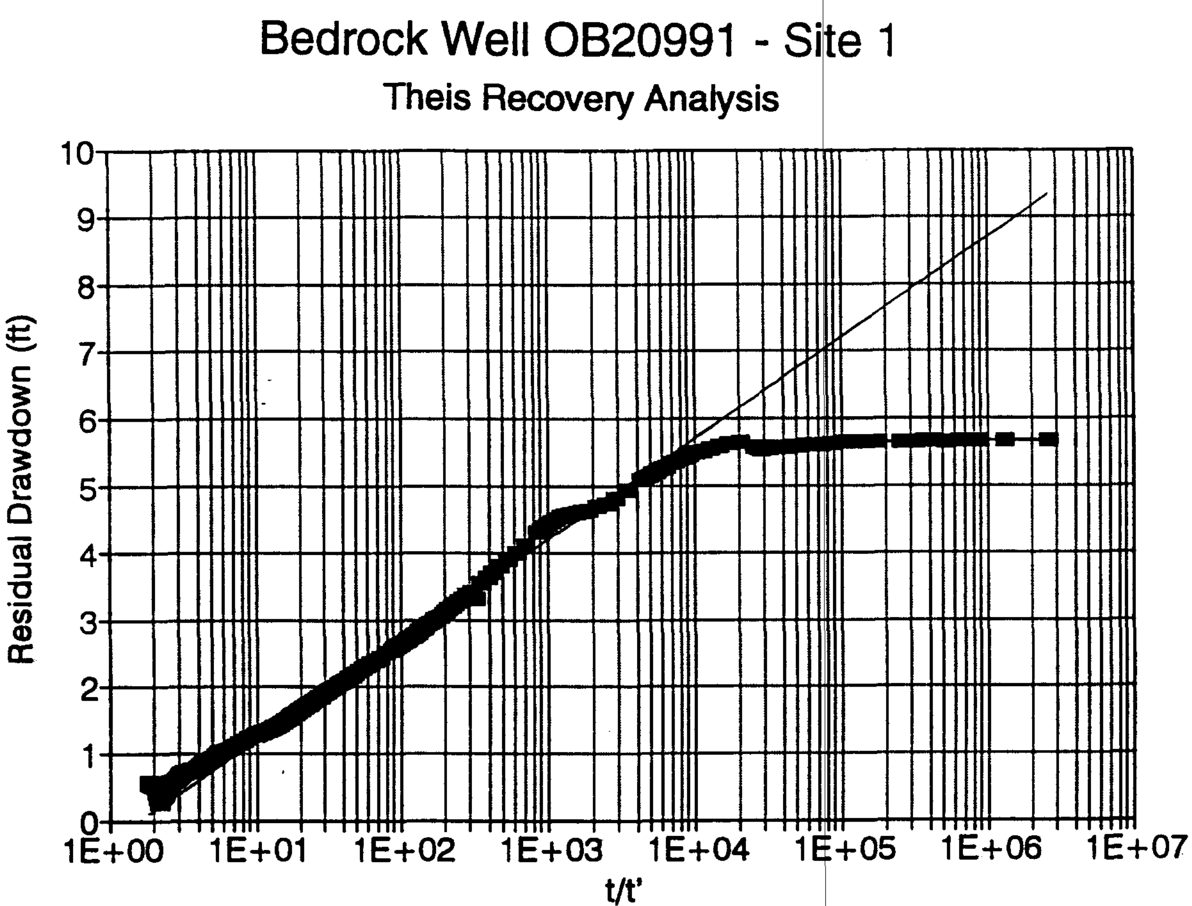
OPERABLE UNIT NO. 2
PHASE II RFI/RI AQUIFER TEST
REPORT

OB20991
Theis Analysis

FIGURE 34 NOVEMBER, 1992



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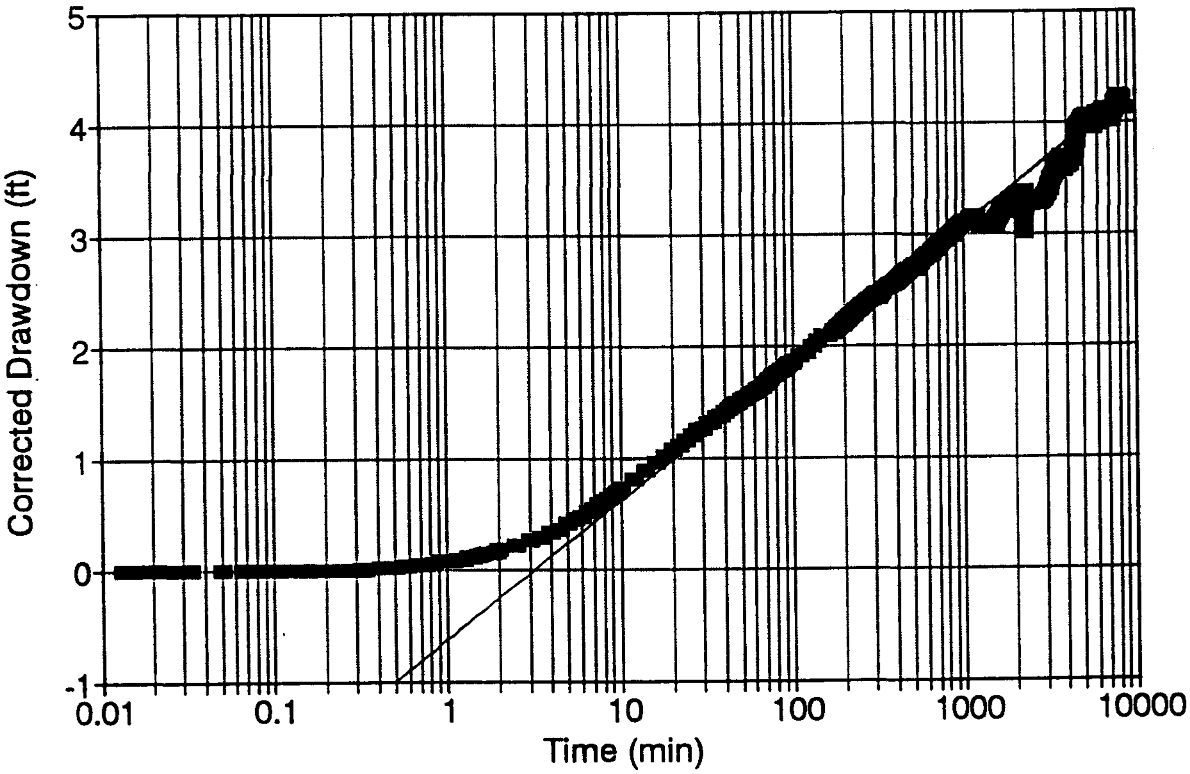
OPERABLE UNIT NO. 2
PHASE II RFI/RI AQUIFER TEST
REPORT

OB20991
Theis Recovery Analysis

FIGURE 35 NOVEMBER, 1992

Bedrock Well OB21091 - Site 1

Cooper - Jacob Analysis



T = 0.030209 ft^2/min
S = 0.0005254

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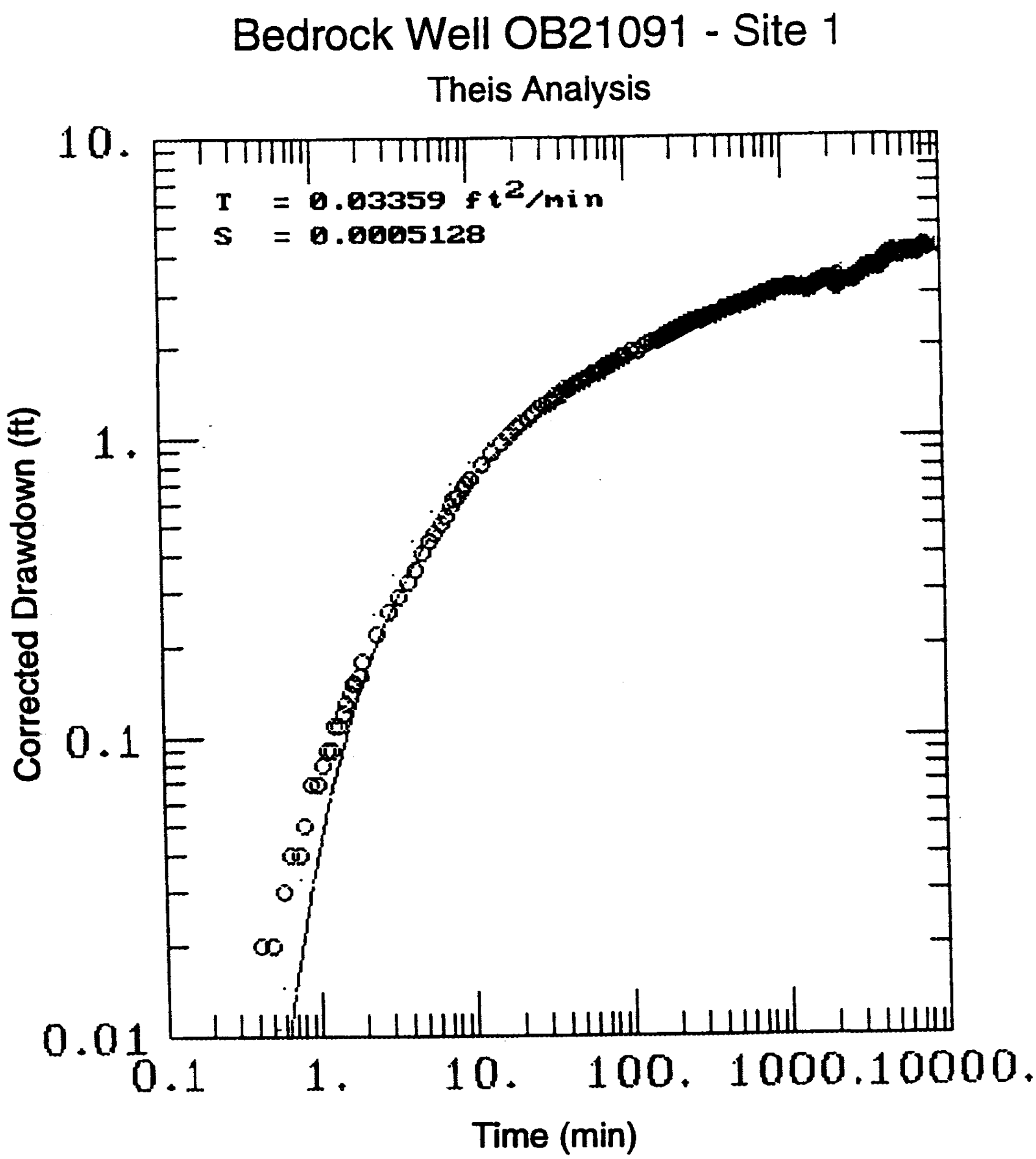
PHASE II RFI/RI AQUIFER TEST
REPORT

OB21091
Cooper-Jacob Analysis

FIGURE 36 NOVEMBER, 1992



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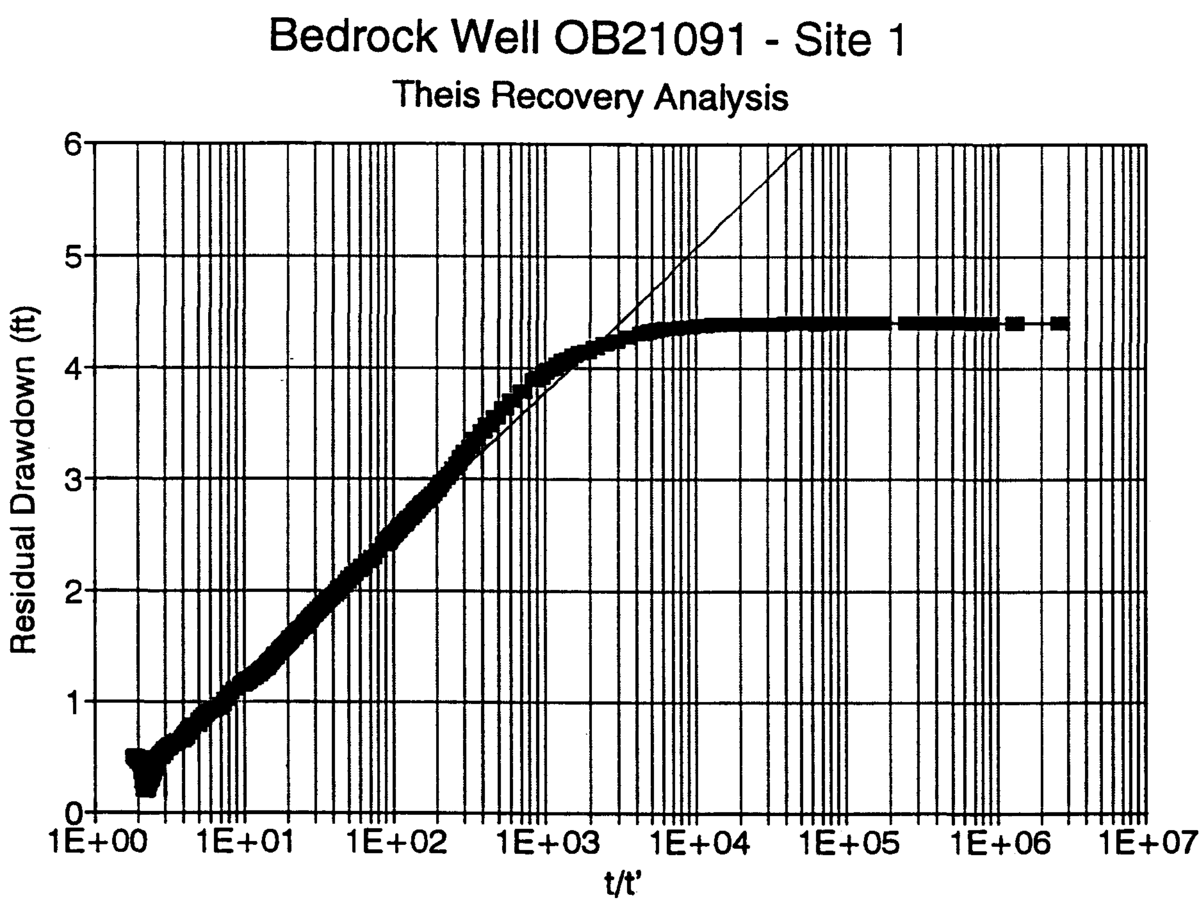
PHASE II RFI/RI AQUIFER TEST
REPORT

OB21091
Theis Analysis

FIGURE 37 NOVEMBER, 1992



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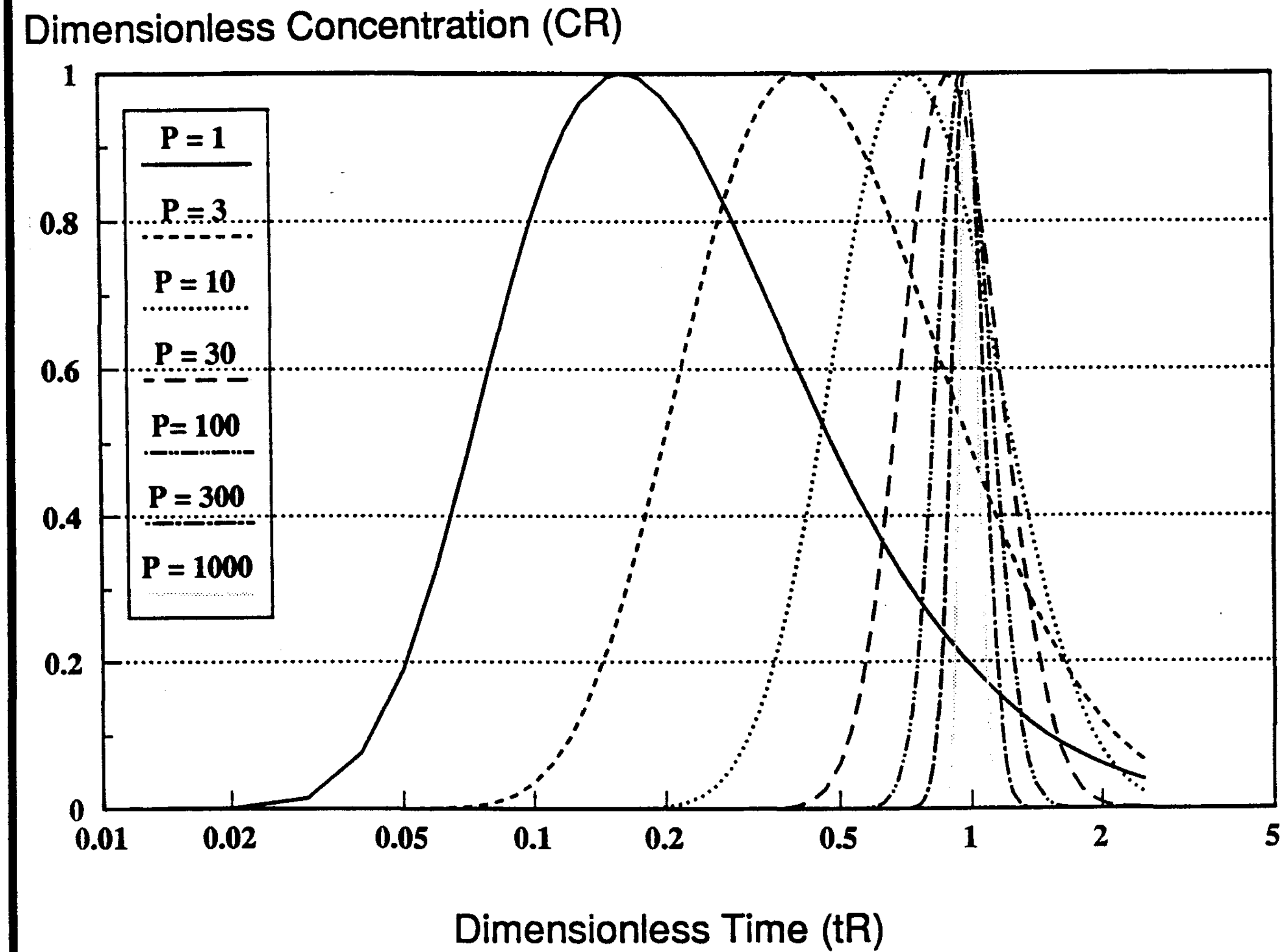
REPORT

OB21091
Theis Recovery Analysis

FIGURE 38 **NOVEMBER, 1992**

Type Curves for Converging Radial Flow Tracer Test

Site 1



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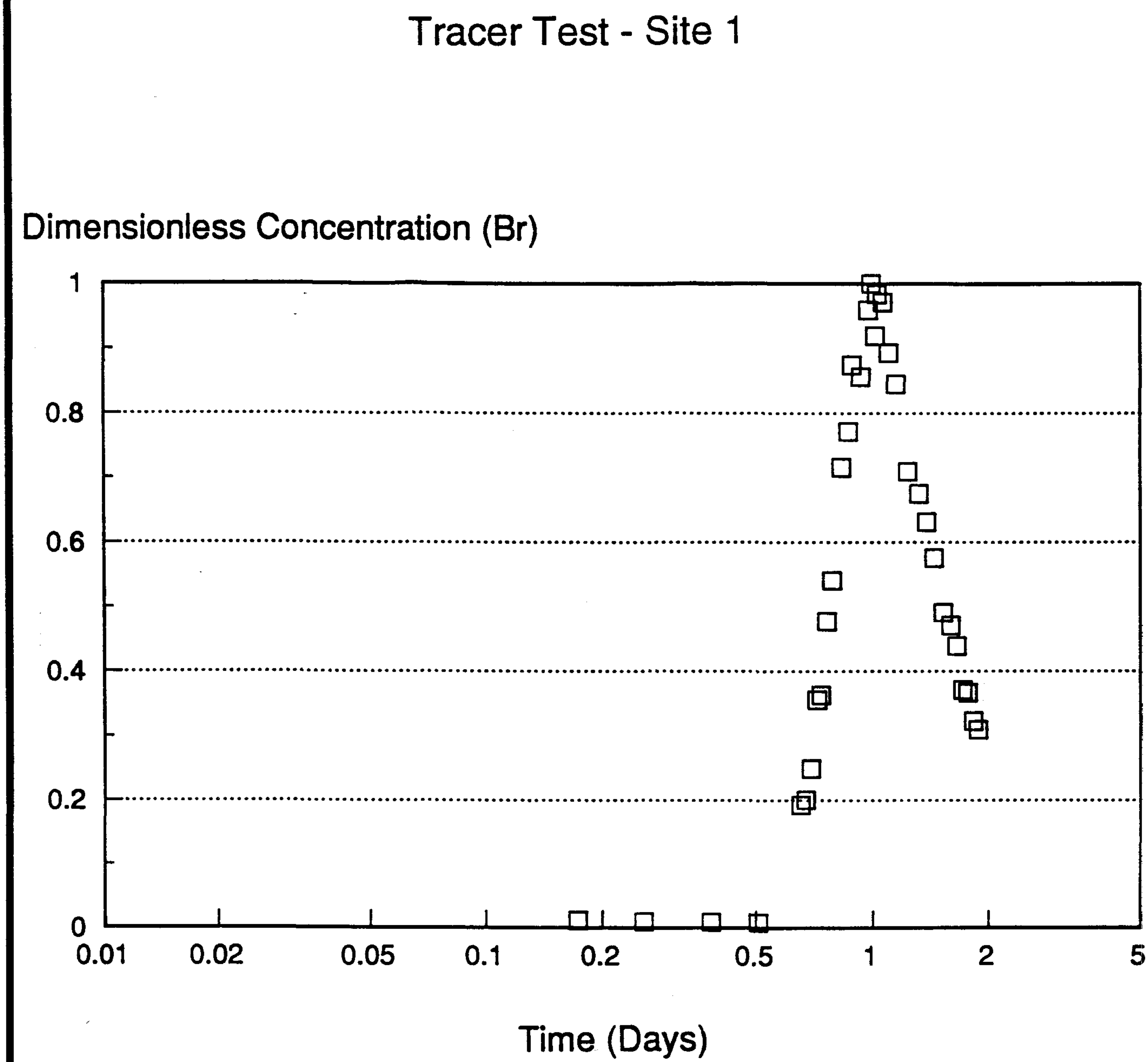
REPORT

Site 1
Type Curve

FIGURE 39 NOVEMBER, 1992



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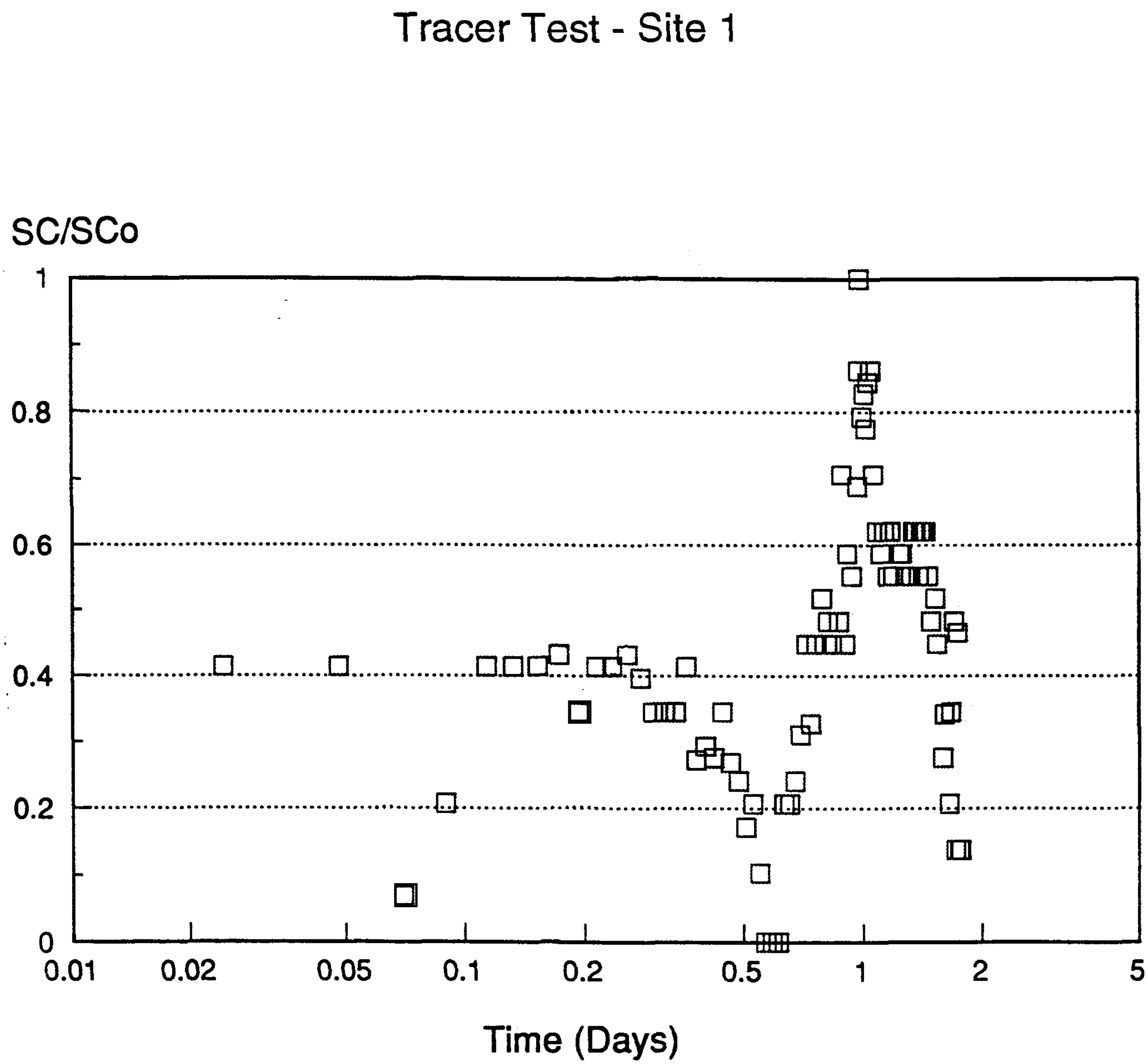
REPORT

Site 1
Lab-Analyzed Bromide Curve

FIGURE 40 NOVEMBER, 1992



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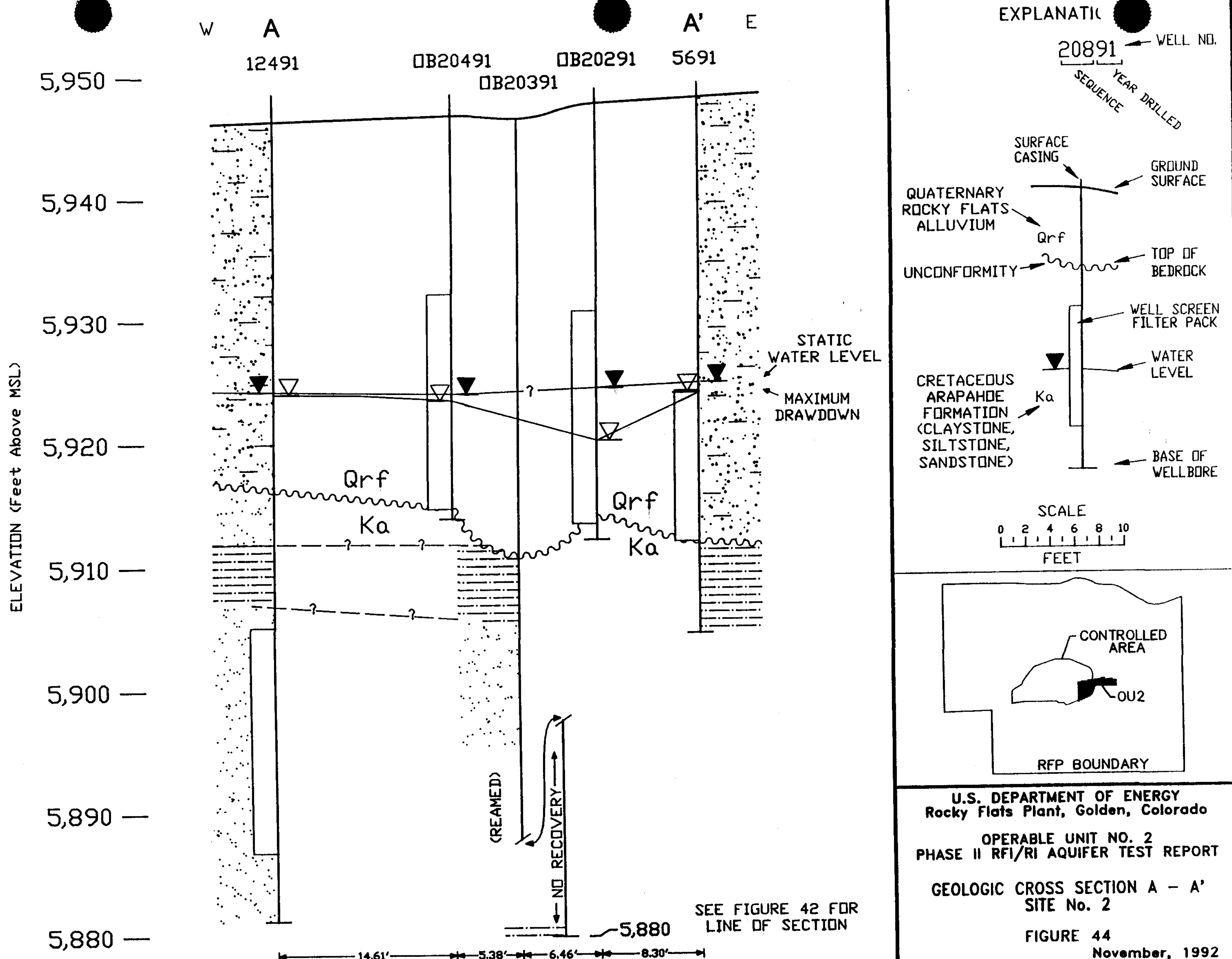
REPORT

Site 1
Field Specific Conductance Curve

FIGURE 41 NOVEMBER, 1992



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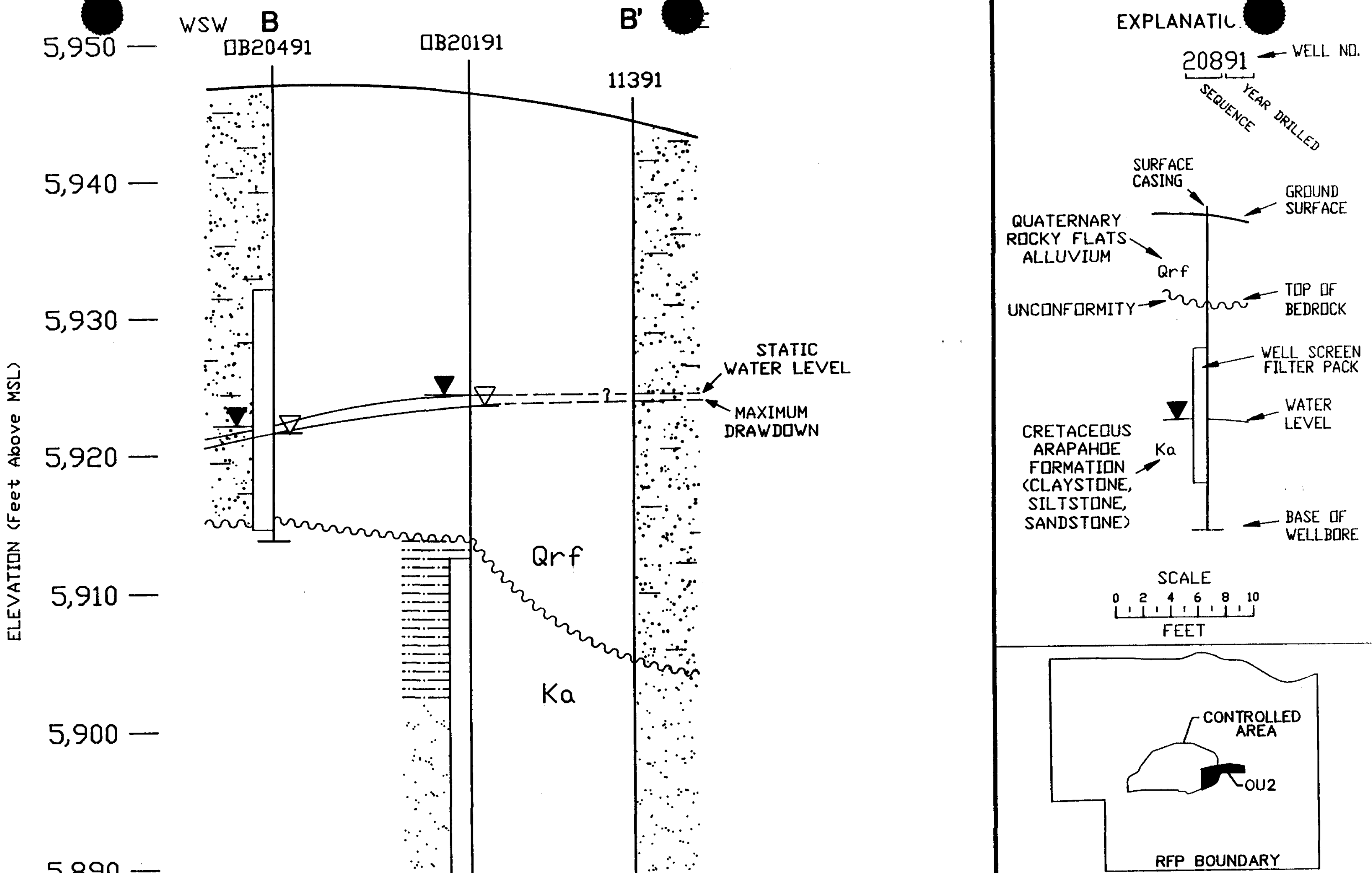
GEOLOGIC CROSS SECTION A – A'
SITE No. 2

FIGURE 44

November, 1992



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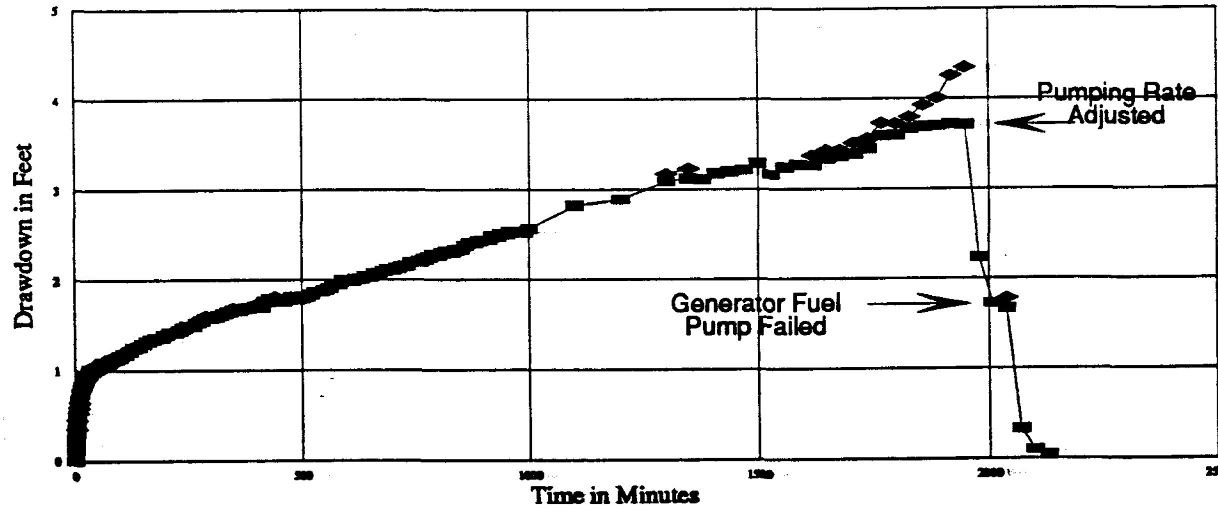
GEOLOGIC CROSS SECTION B – B'
SITE No. 2

FIGURE 45

November, 1992

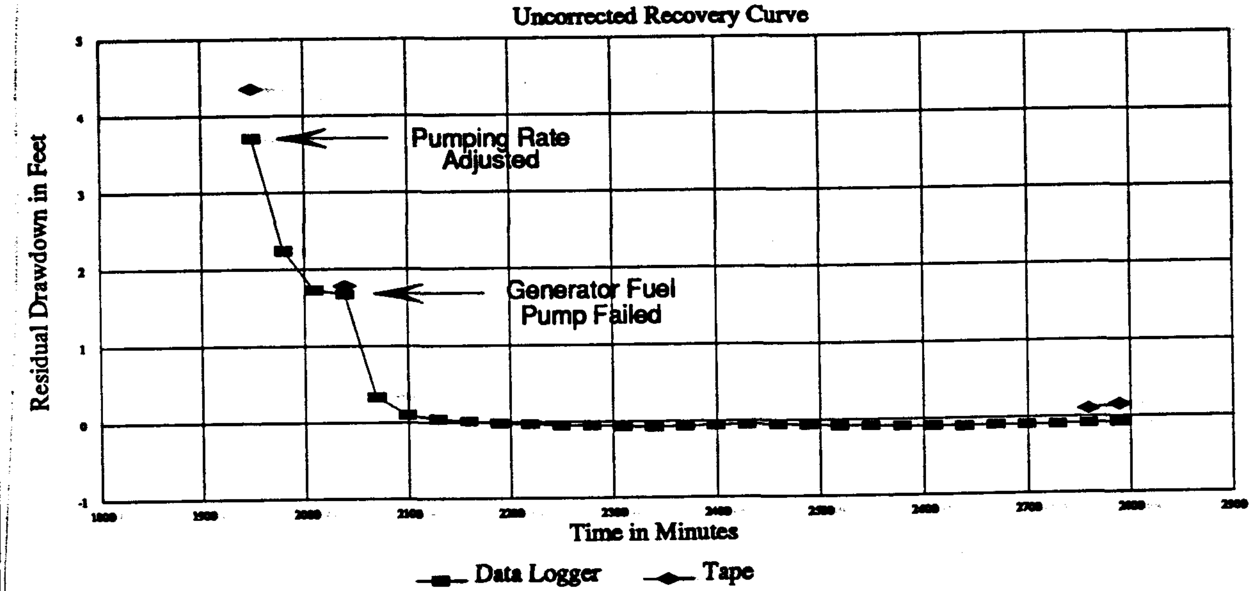
Alluvial Well OB20291-Site 2

Uncorrected Time-Drawdown Curve



From 9:17, June 23,1992
to 20:46, June 24, 1992

Uncorrected Recovery Curve



From 17:46, June 24,1992
to 8:26, June 25, 1992

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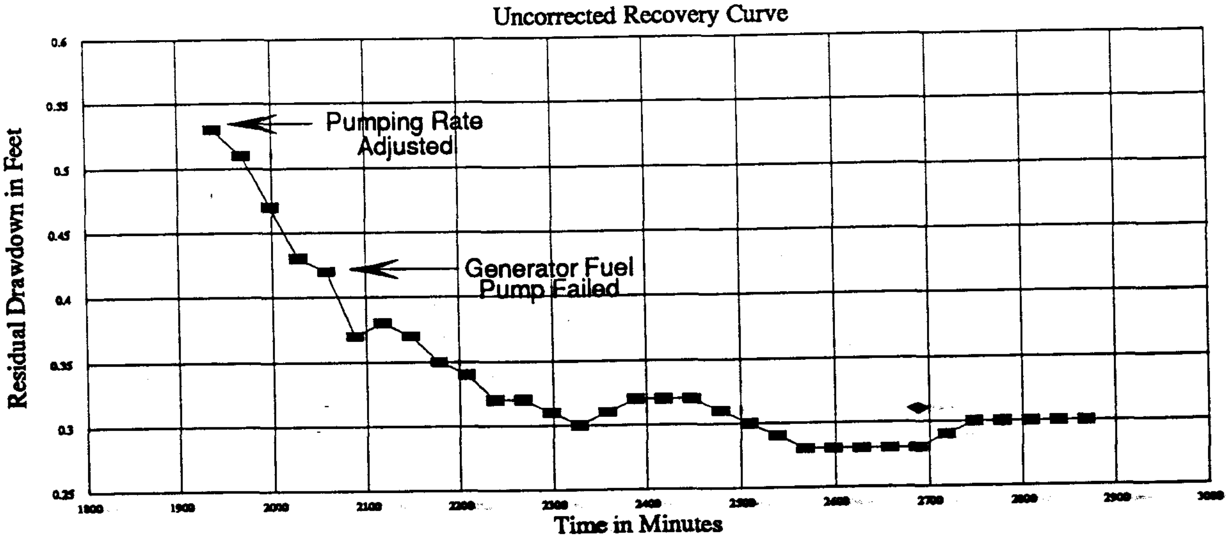
OPERABLE UNIT NO. 2
PHASE II RFI/RI AQUIFER TEST REPORT

Operational Data
OB20291 Hydrographs

FIGURE 46 NOVEMBER, 1992

Alluvial Well 20491-Site 2

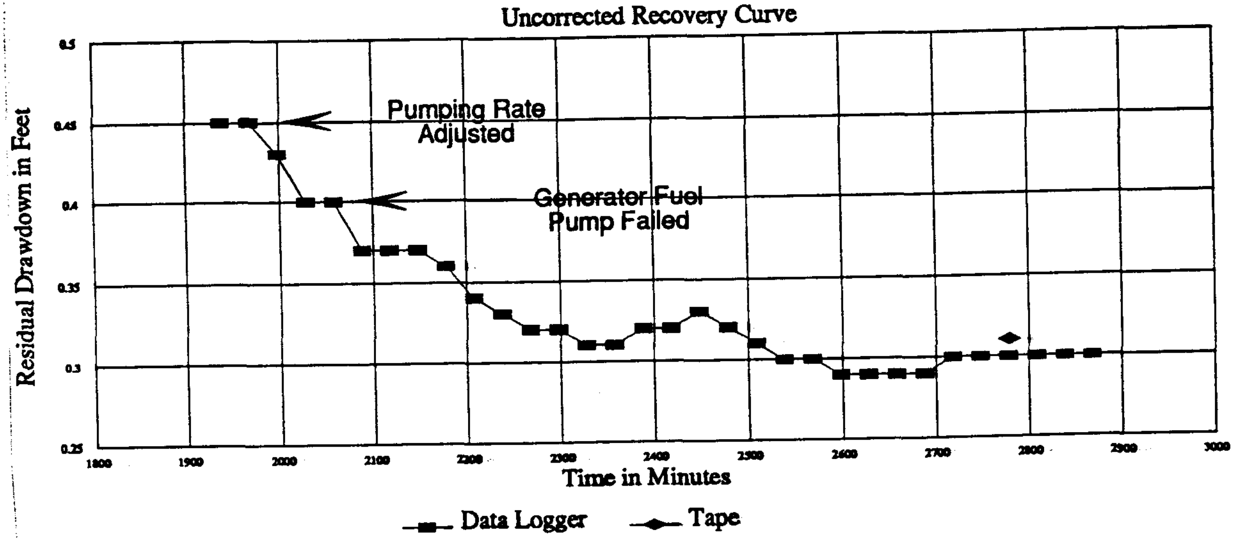
Uncorrected Recovery Curve



From 17:28, June 24, 1992
to 9:45, June 25, 1992

Bedrock Well 21191-Site 2

Uncorrected Recovery Curve



From 18:35, June 24, 1992
to 9:25, June 25, 1992

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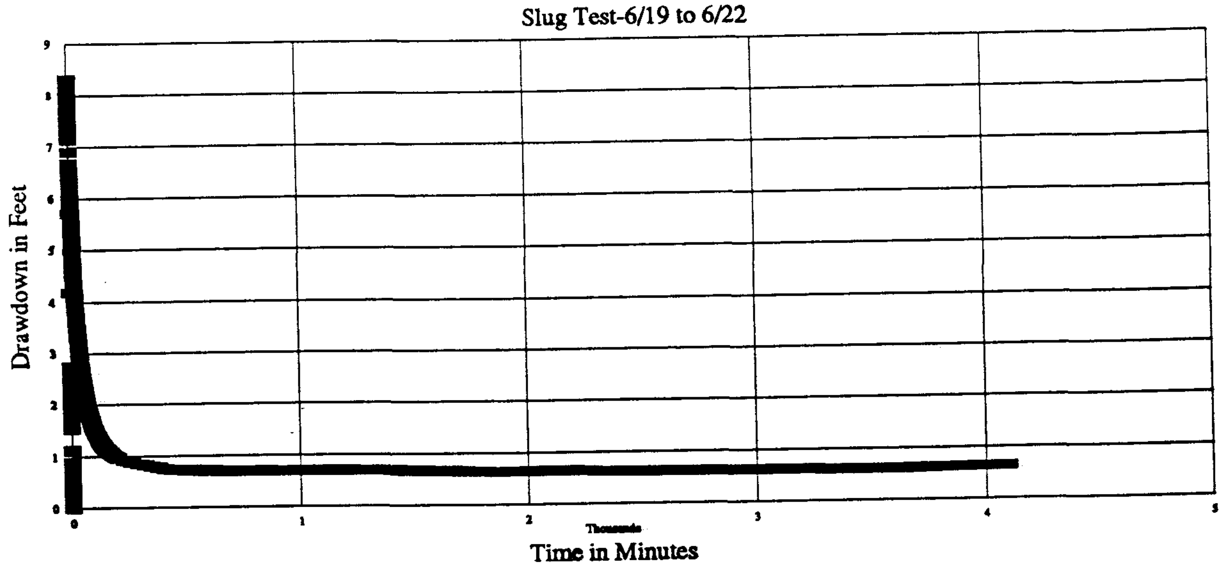
PHASE II RFI/RI AQUIFER TEST
REPORT

Recovery and Background
Water Level Trends for
OB20491 and OB21191

FIGURE 47 NOVEMBER, 1992

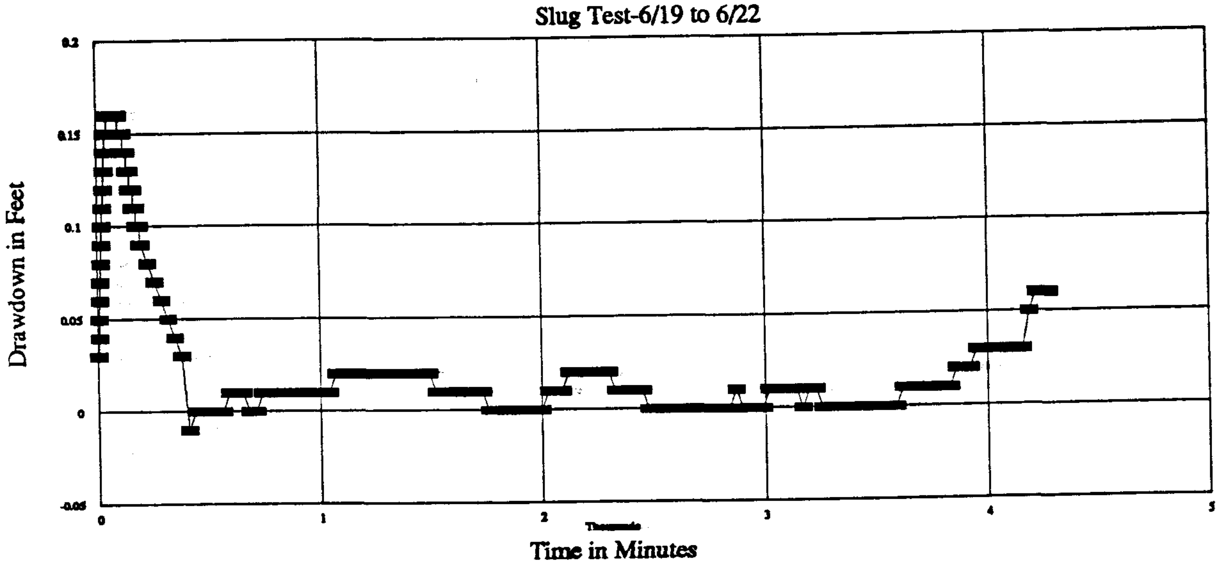
Bedrock Well 20191-Site 2

Slug Test-6/19 to 6/22



Bedrock Well 12491-Site 2

Slug Test-6/19 to 6/22

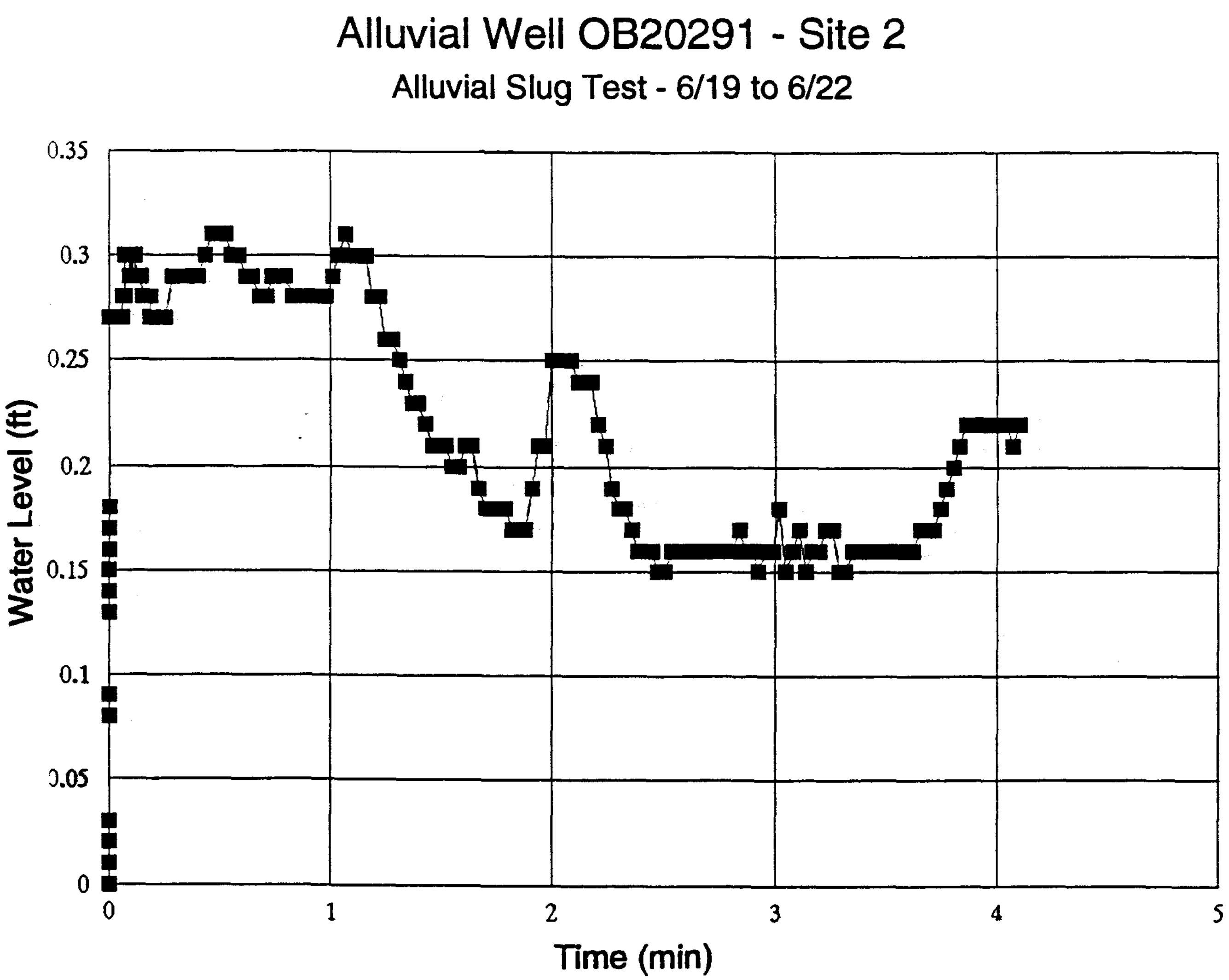


U.S. DEPARTMENT OF ENERGY
Rocky Flats Plant, Golden, Colorado

OPERABLE UNIT NO. 2
PHASE II RFI/RI AQUIFER TEST
REPORT

Slug Test Hydrographs
for OB20191 and 12491

FIGURE 48 NOVEMBER, 1992

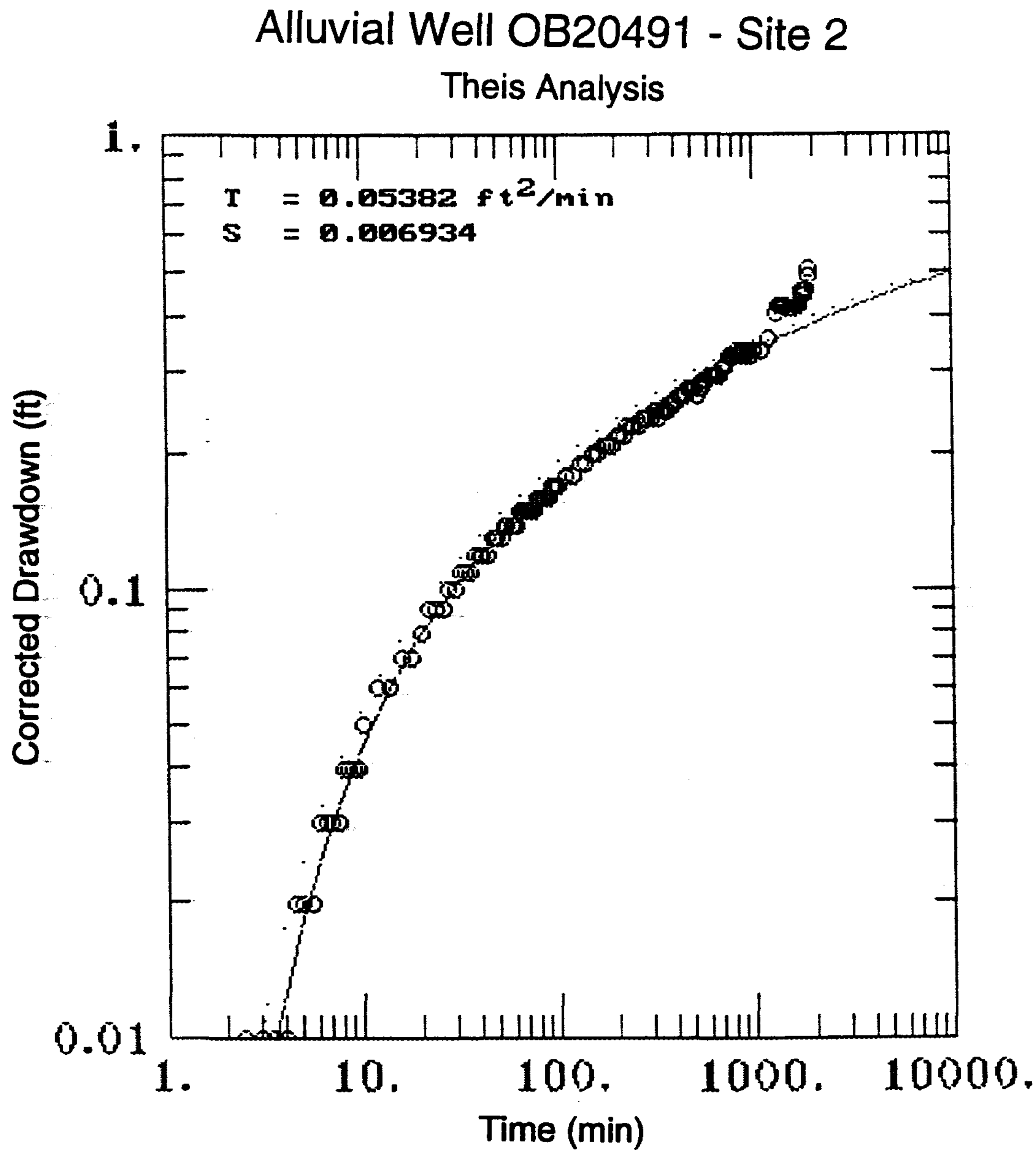


U.S. DEPARTMENT OF ENERGY
Rocky Flats Plant, Golden, Colorado

OPERABLE UNIT NO. 2
PHASE II RFI/RI AQUIFER TEST REPORT

Slug Test Hydrograph for OB20291

FIGURE 49 NOVEMBER, 1992



U.S. DEPARTMENT OF ENERGY
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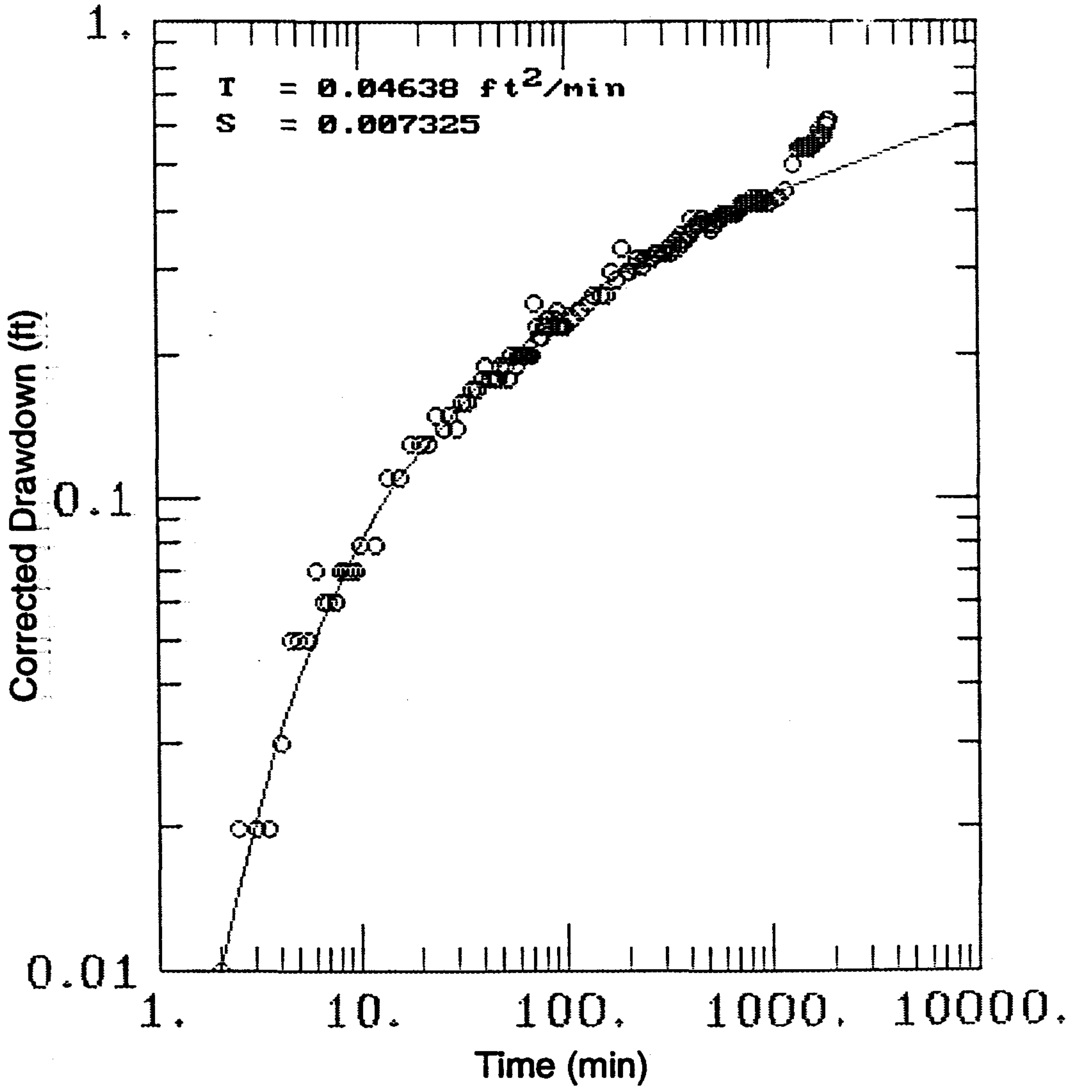
PHASE II RFI/RI AQUIFER TEST
REPORT

OB20491
Theis Analysis

FIGURE 50 NOVEMBER, 1992

Alluvial Well 5691 - Site 2

Theis Analysis



U.S. DEPARTMENT OF ENERGY
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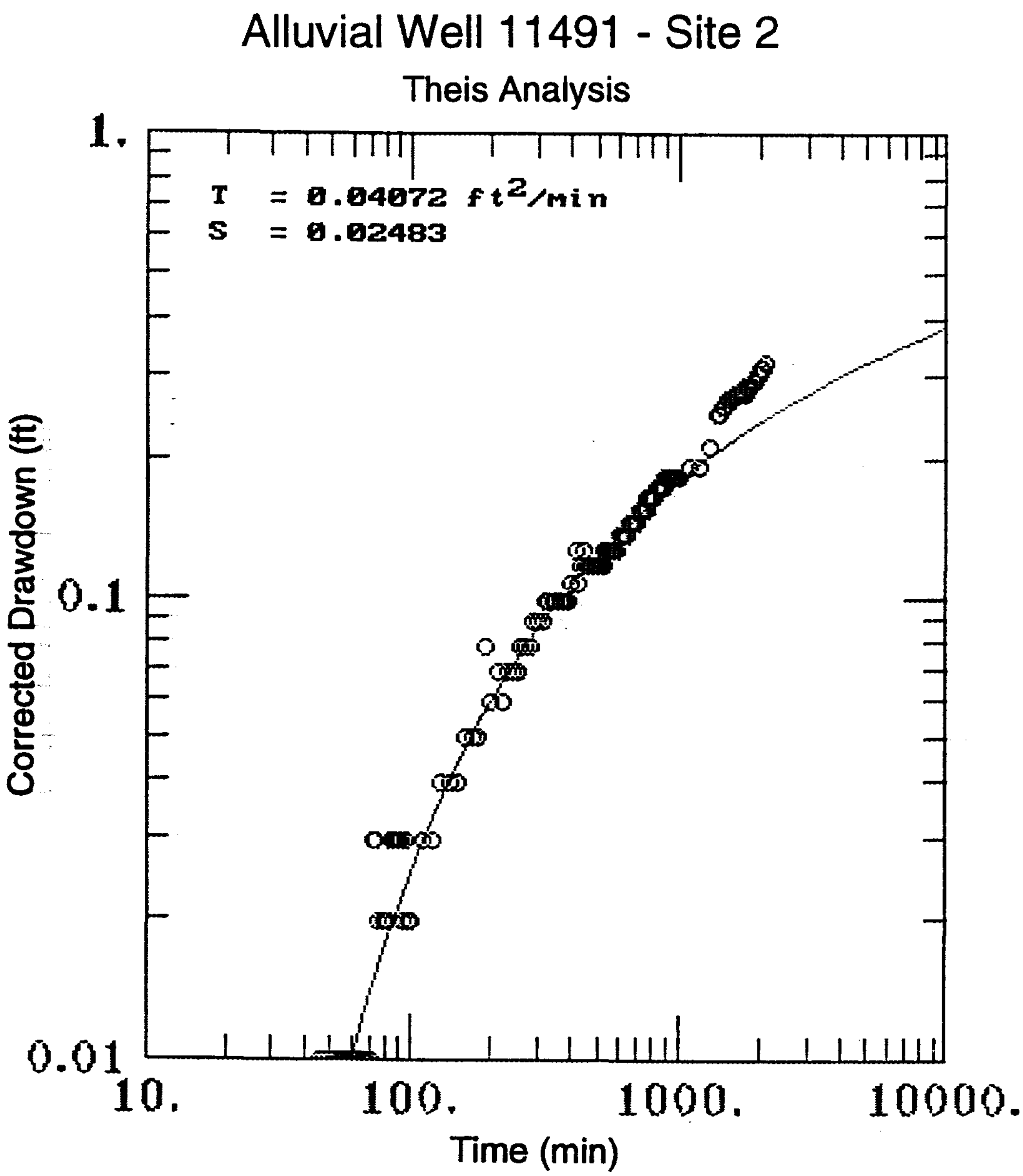
PHASE II RFI/RI AQUIFER TEST REPORT

5691
Theis Analysis

FIGURE 51 NOVEMBER, 1992



U.S. DEPARTMENT OF ENERGY
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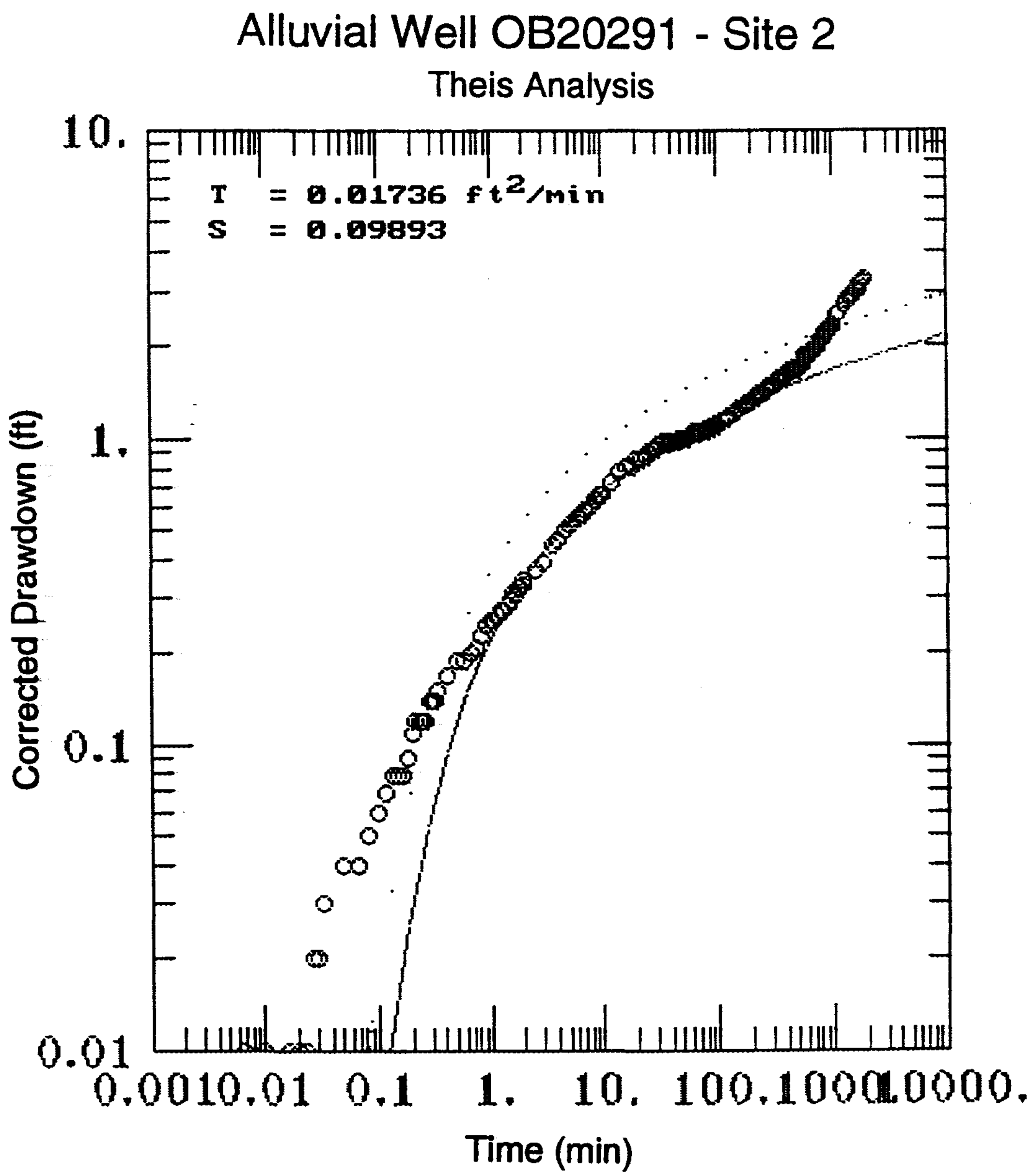
PHASE II RFI/RI AQUIFER TEST REPORT

11491
Theis Analysis

FIGURE 52 NOVEMBER, 1992



U.S. DEPARTMENT OF ENERGY
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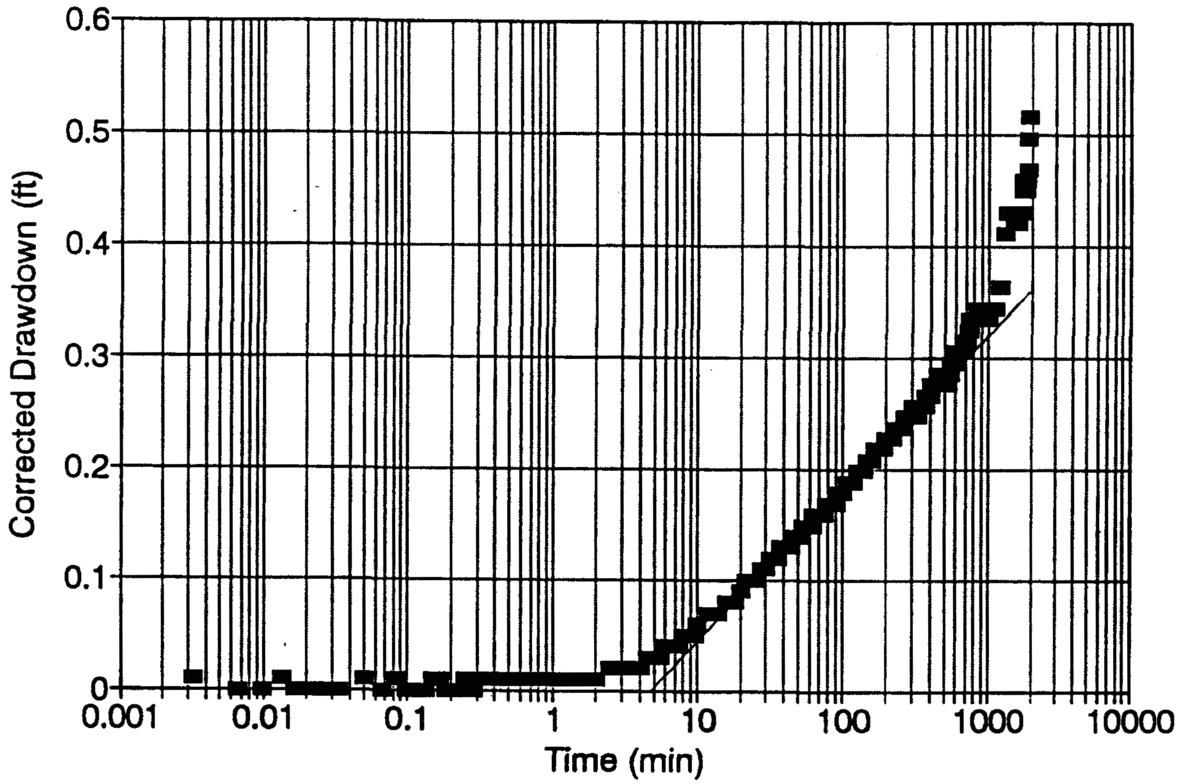
PHASE II RFI/RI AQUIFER TEST REPORT

OB20291
Theis Analysis

FIGURE 53 NOVEMBER, 1992

Alluvial Well OB20491 - Site 2

Cooper - Jacob Analysis



$T = .06223\ ft^2/min$

$S = .004813$

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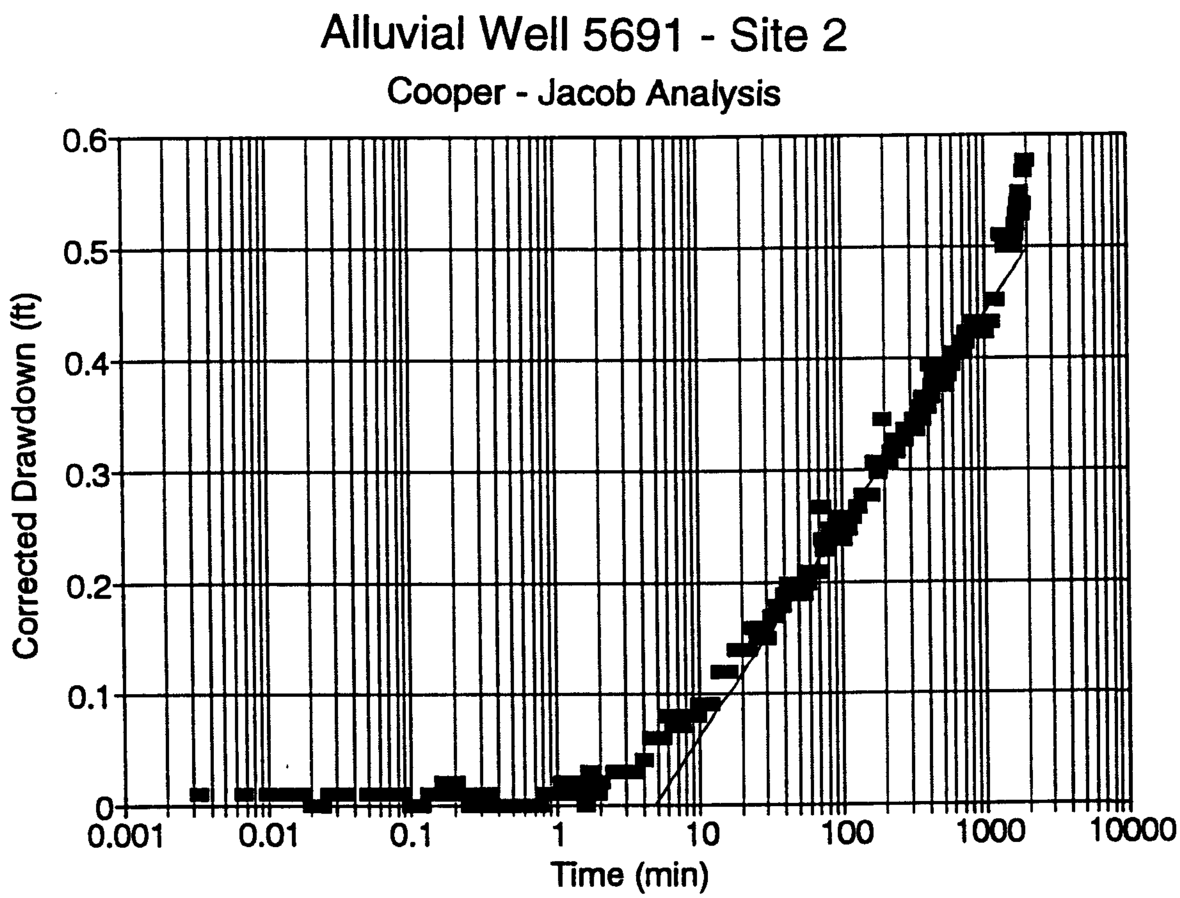
PHASE II RFI/RI AQUIFER TEST REPORT

OB20491
Cooper-Jacob Analysis

FIGURE 55 NOVEMBER, 1992



T = .0451 ft^2/min
S = .007055

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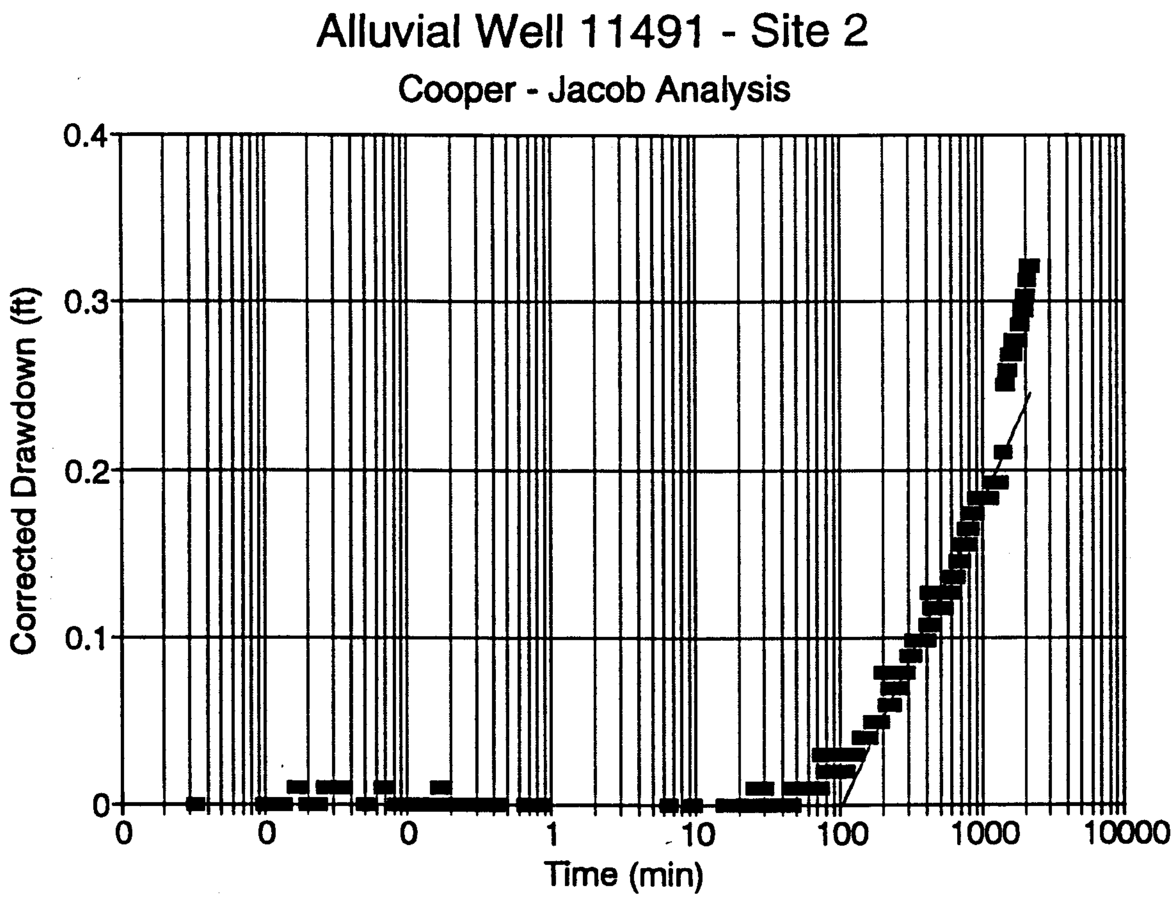
Rocky Flats Plant, Golden, Colorado

OPERABLE UNIT NO. 2
PHASE II RFI/RI AQUIFER TEST
REPORT

5691
Cooper-Jacob Analysis

FIGURE 56 NOVEMBER, 1992



T = .04599 ft^2/min
S = .01906

U.S. DEPARTMENT OF ENERGY
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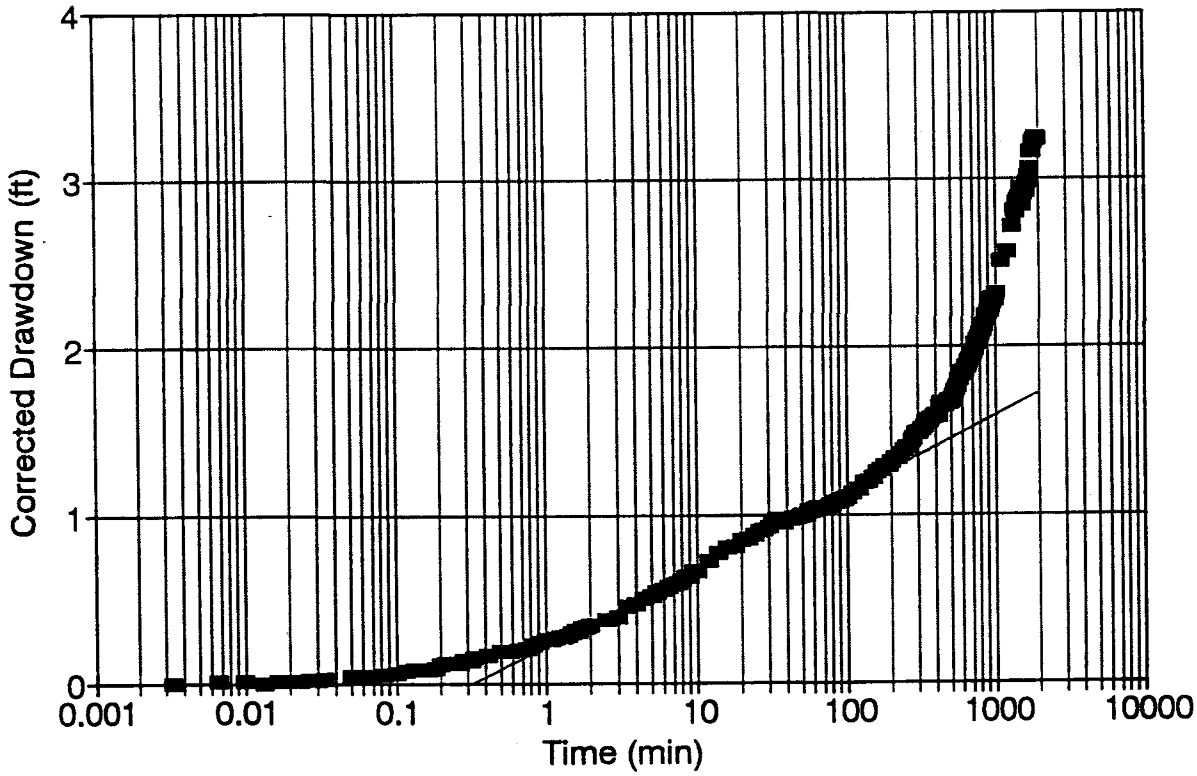
OPERABLE UNIT NO. 2
PHASE II RFI/RI AQUIFER TEST REPORT

11491
Cooper-Jacob Analysis

FIGURE 57 NOVEMBER, 1992

Alluvial Well OB20291 - Site 2

Cooper - Jacob Analysis



$T = .01875\ ft^2/min$

$S = .08100$

U.S. DEPARTMENT OF ENERGY
Rocky Flats Plant, Golden, Colorado

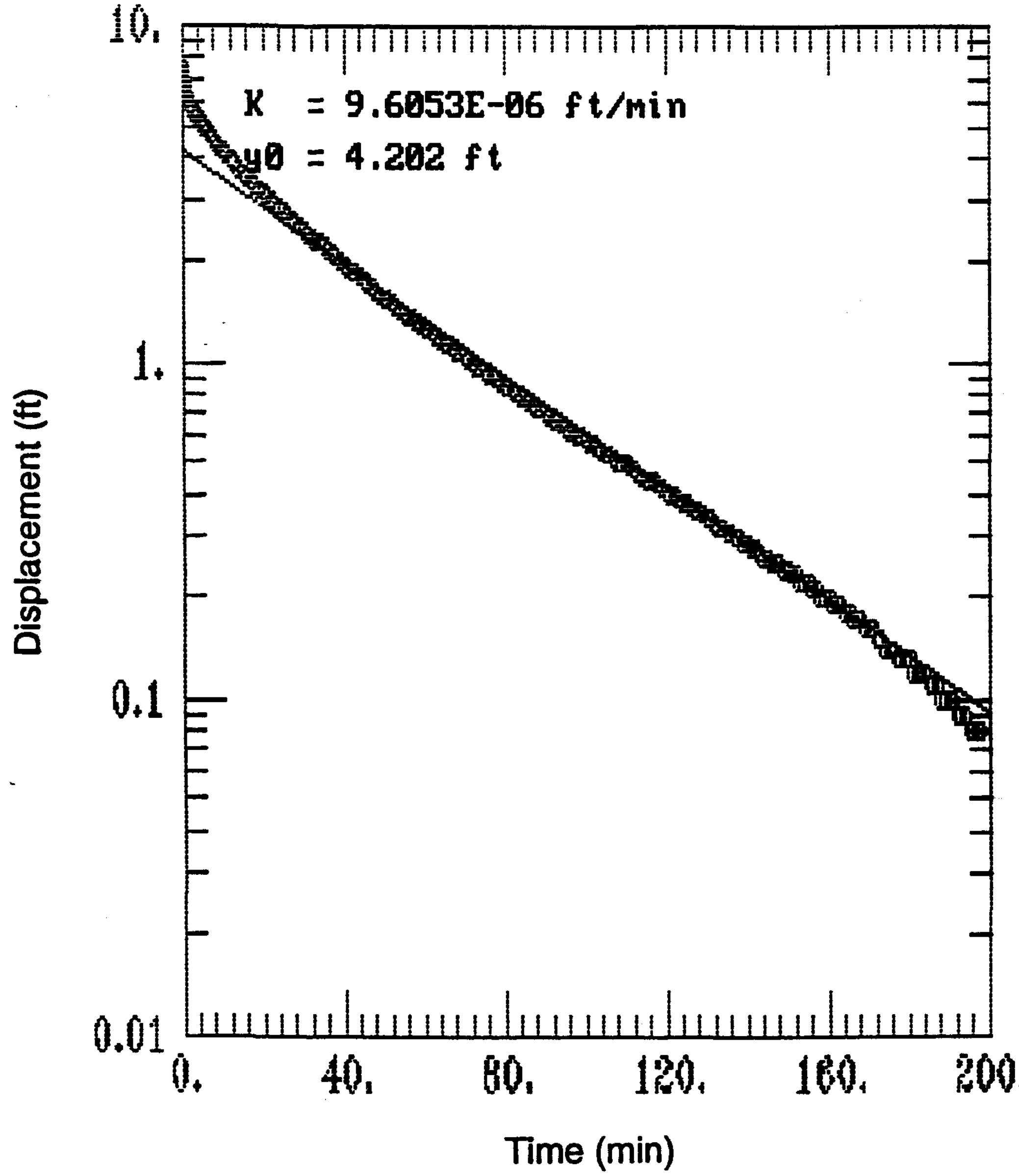
OPERABLE UNIT NO. 2
PHASE II RFI/RI AQUIFER TEST REPORT

OB20291
Cooper-Jacob Analysis

FIGURE 58 NOVEMBER, 1992

Alluvial Well OB20191 - Site 2

Slug Test Analysis

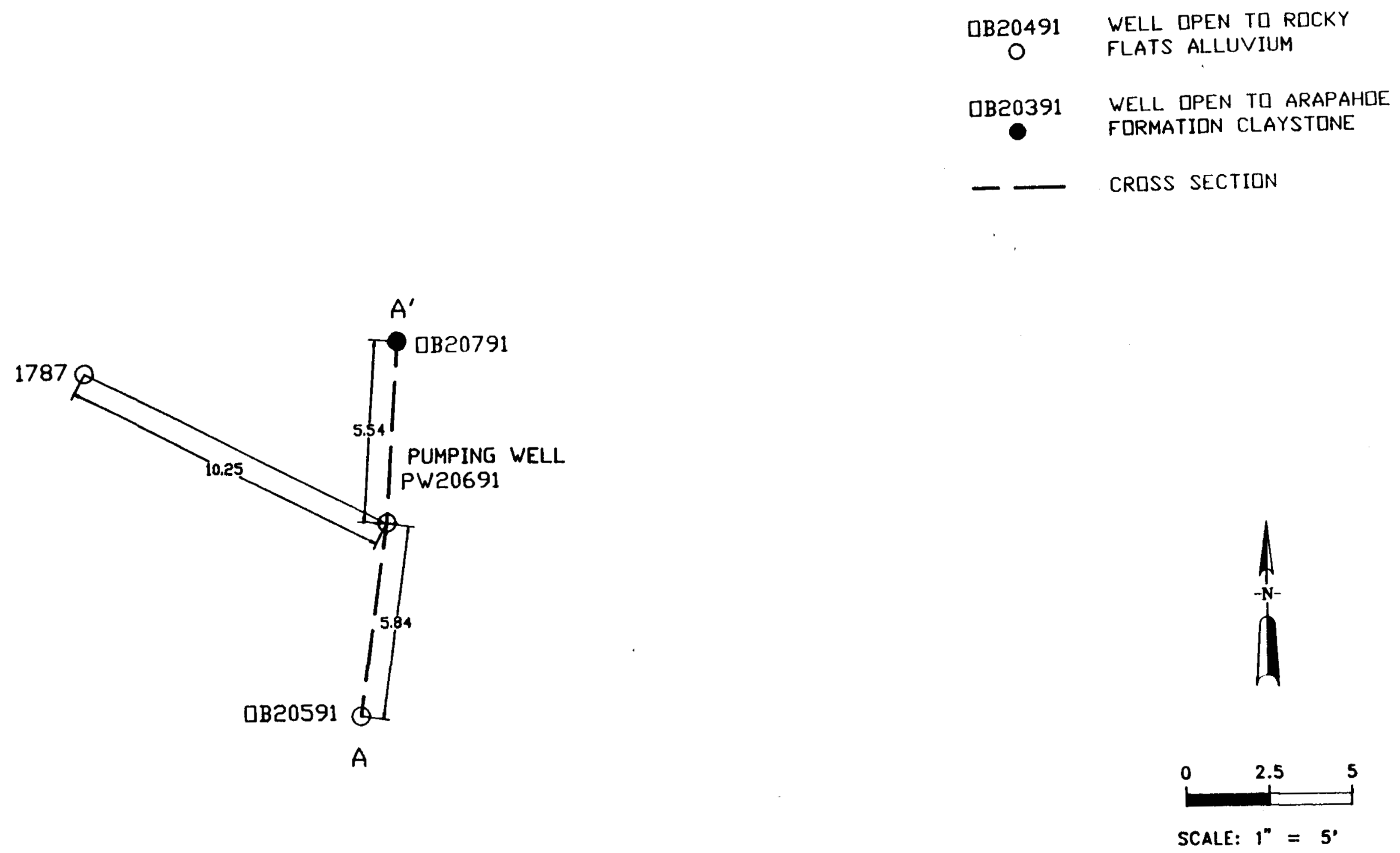


U.S. DEPARTMENT OF ENERGY
Rocky Flats Plant, Golden, Colorado

OPERABLE UNIT NO. 2
PHASE II RFI/RI AQUIFER TEST REPORT

OB20191
Slug Test Analysis

FIGURE 59 NOVEMBER, 1992



U.S. DEPARTMENT OF ENERGY
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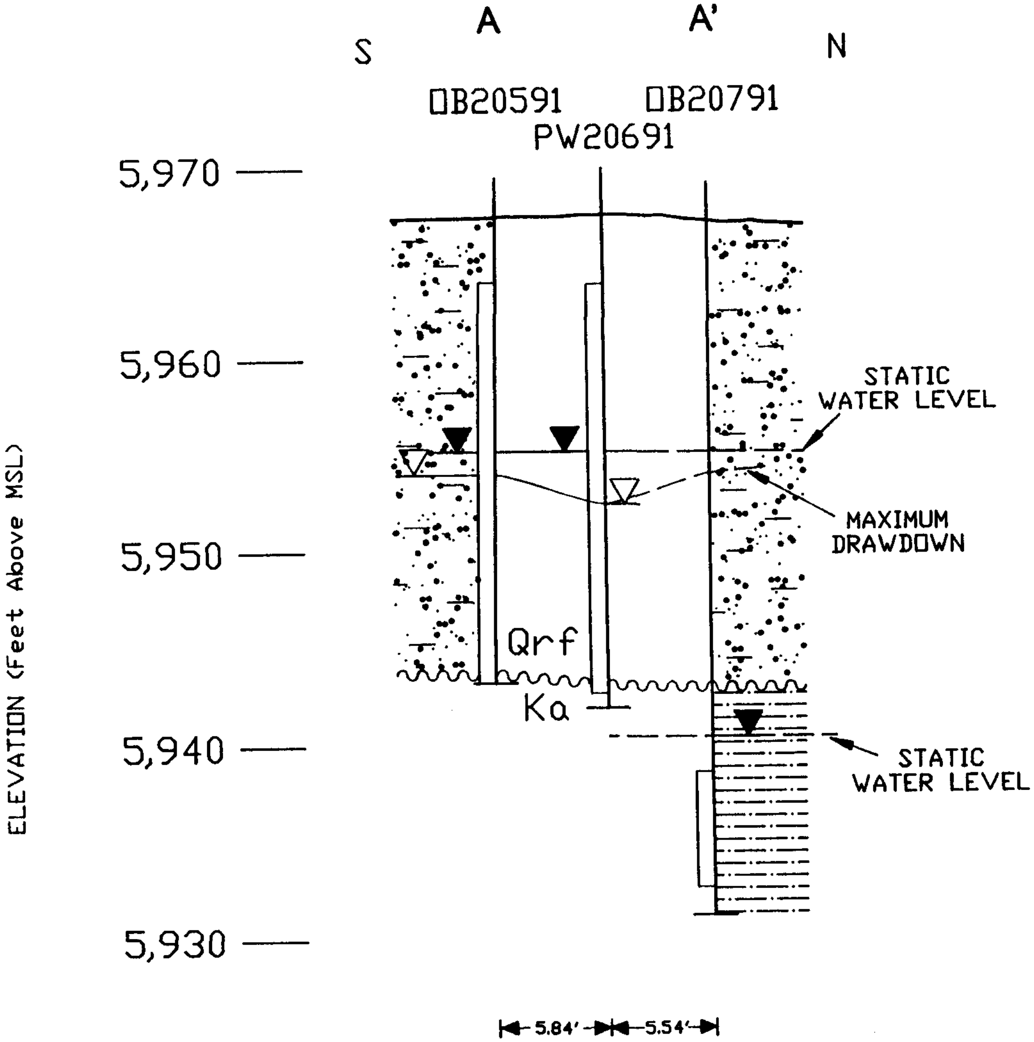
TEST REPORT

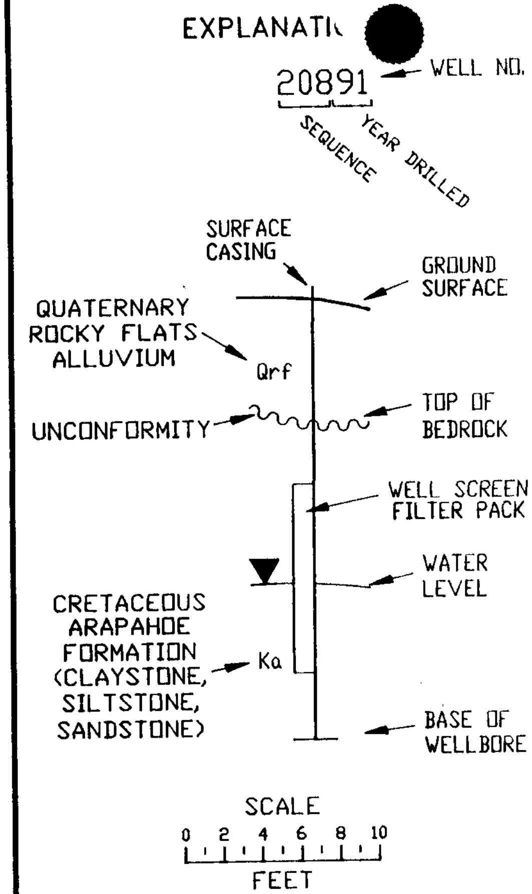
SITE No. 3 WELL FIELD

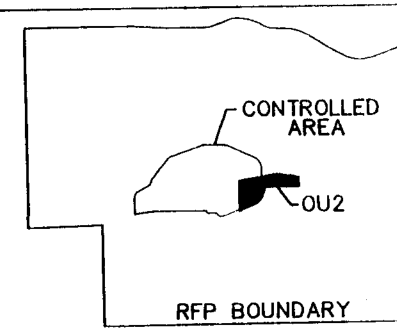
FIGURE 60

August, 1992



SEE FIGURE 60 FOR LINE OF SECTION





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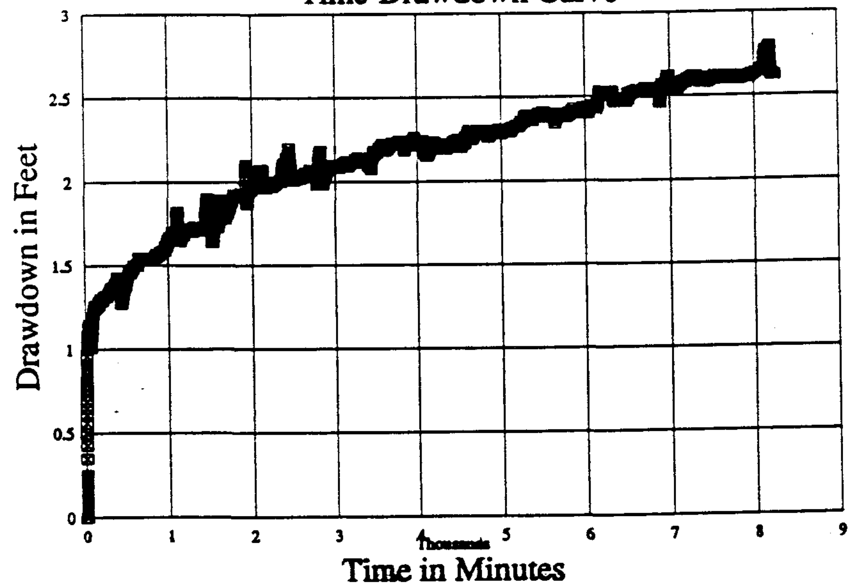
GEOLOGIC CROSS SECTION A – A'
SITE No. 3

FIGURE 61

August, 1992

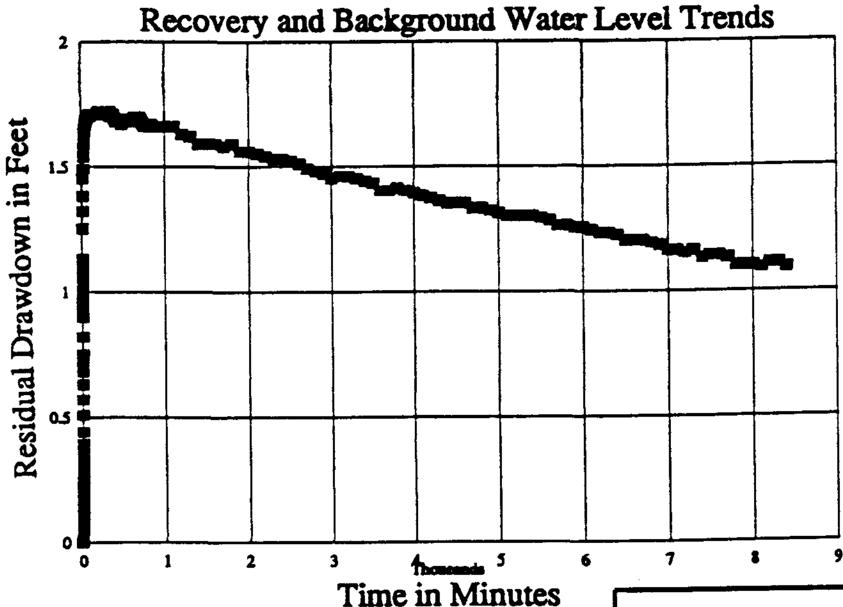
Alluvial Well PW20691-Site 3

Time-Drawdown Curve



From 15:49, May 20, 1992
to 9:20, May 26, 1992.

Recovery and Background Water Level Trends



From 9:38, May 26, 1992
to 5:49, June 1, 1992.

U.S. DEPARTMENT OF ENERGY
Rocky Flats Plant, Golden, Colorado

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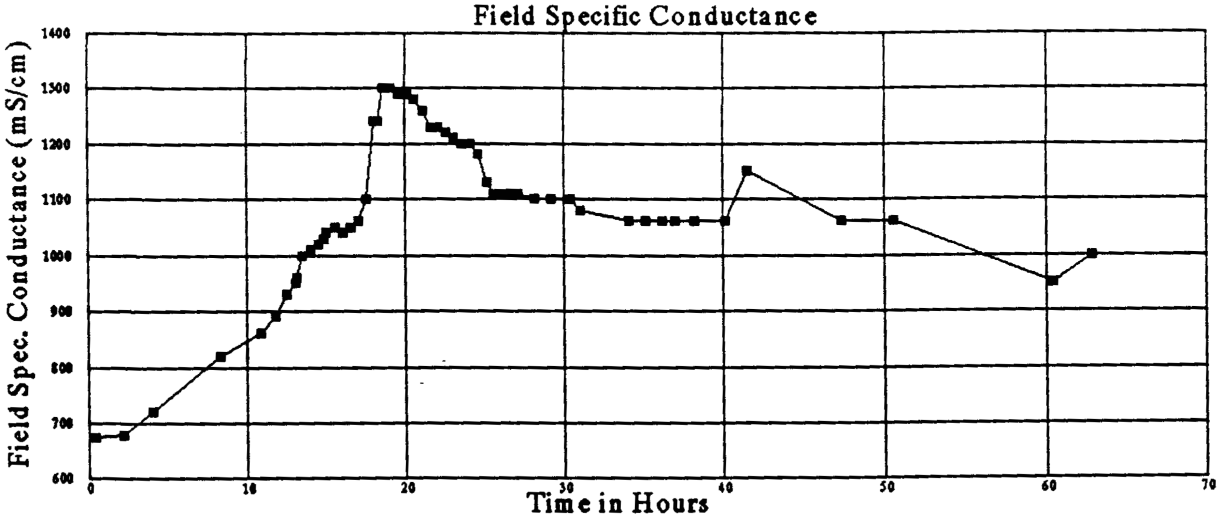
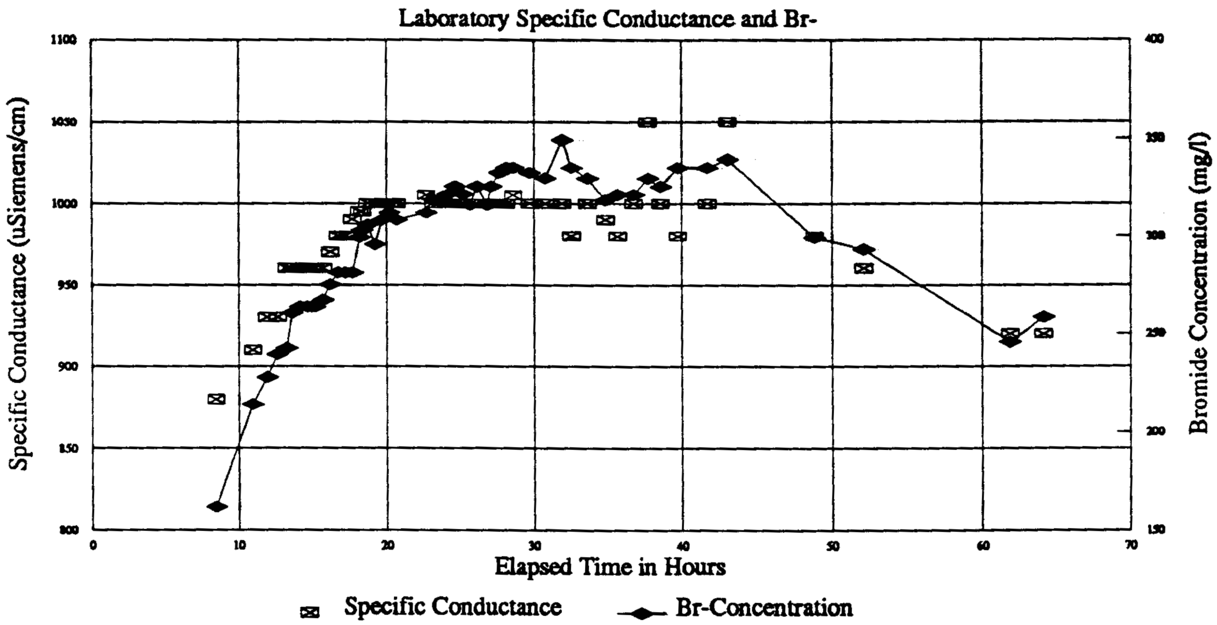
PHASE II RFI/RI AQUIFER TEST
REPORT

Drawdown, Recovery and Background
Water Level Trend for PW20691

FIGURE 62 NOVEMBER, 1992

Site 3 Tracer Test Data





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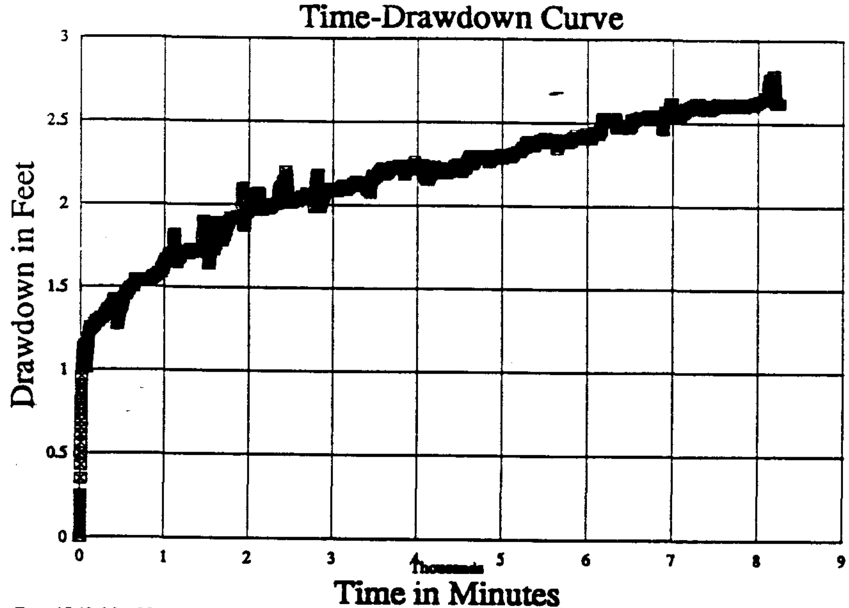
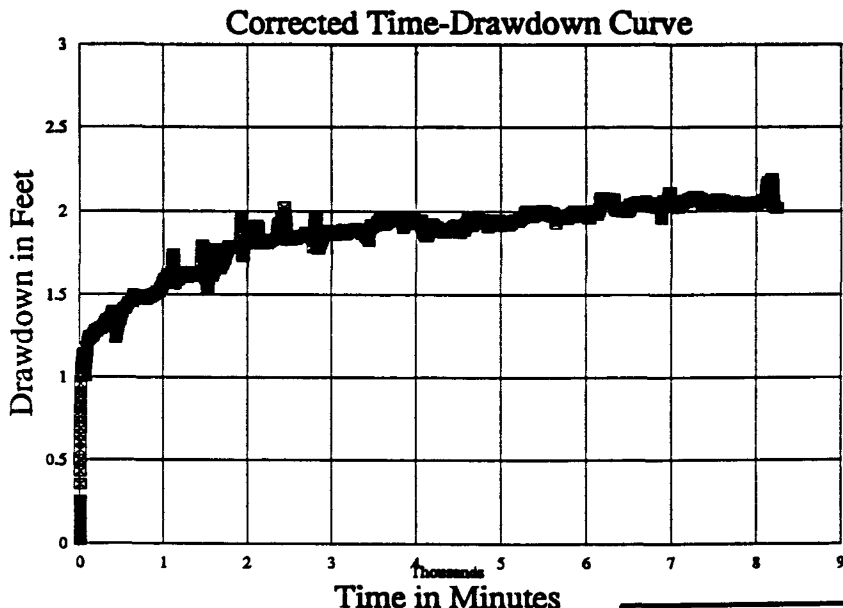
Tracer Test Data
for Site 3

FIGURE 63 NOVEMBER, 1992

Alluvial Well PW20691-Site 3



From 15:49, May 20, 1992
to 9:20, May 26, 1992.



From 15:49, May 20, 1992
to 9:20, May 26, 1992.

U.S. DEPARTMENT OF ENERGY
Rocky Flats Plant, Golden, Colorado

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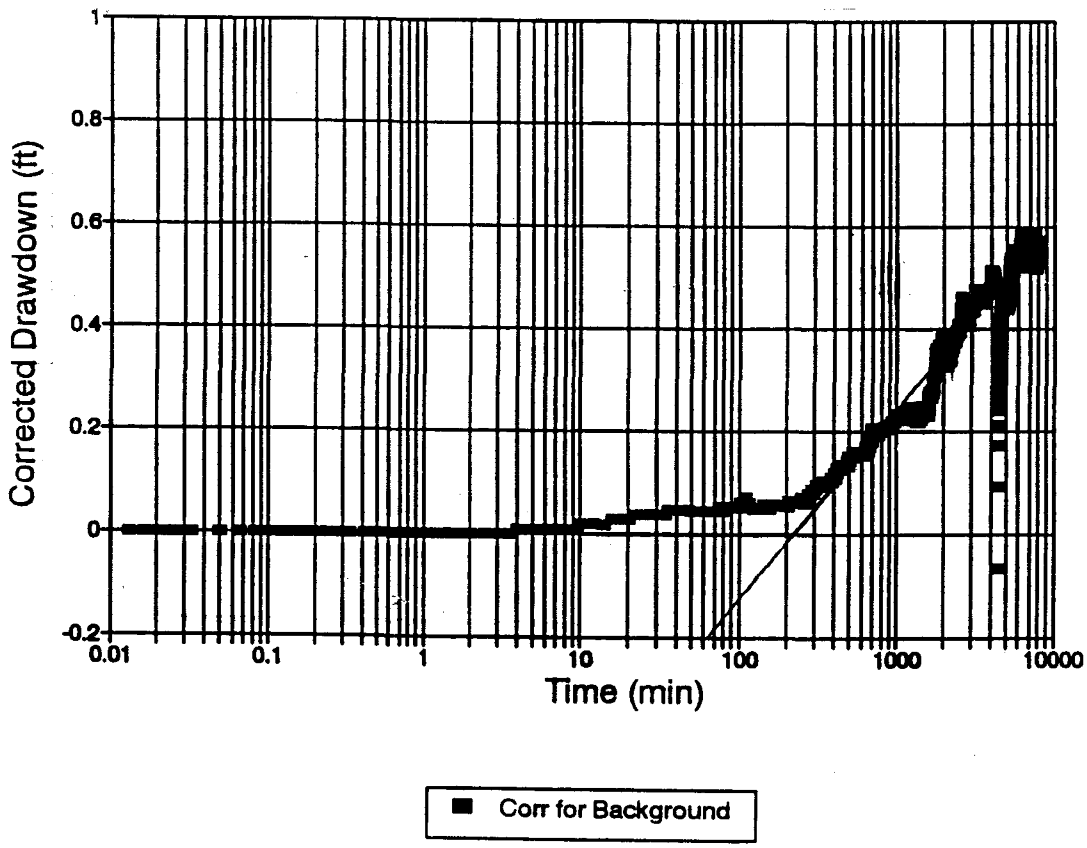
PHASE II RFI/RI AQUIFER TEST REPORT

Uncorrected and Corrected Time Drawdown Curves for PW20691

FIGURE 64 NOVEMBER, 1992

Alluvial Well OB20591 - Site 3

Cooper - Jacob Analysis



$T = .003716\ ft^2/min$
$S = .05411$

U.S. DEPARTMENT OF ENERGY
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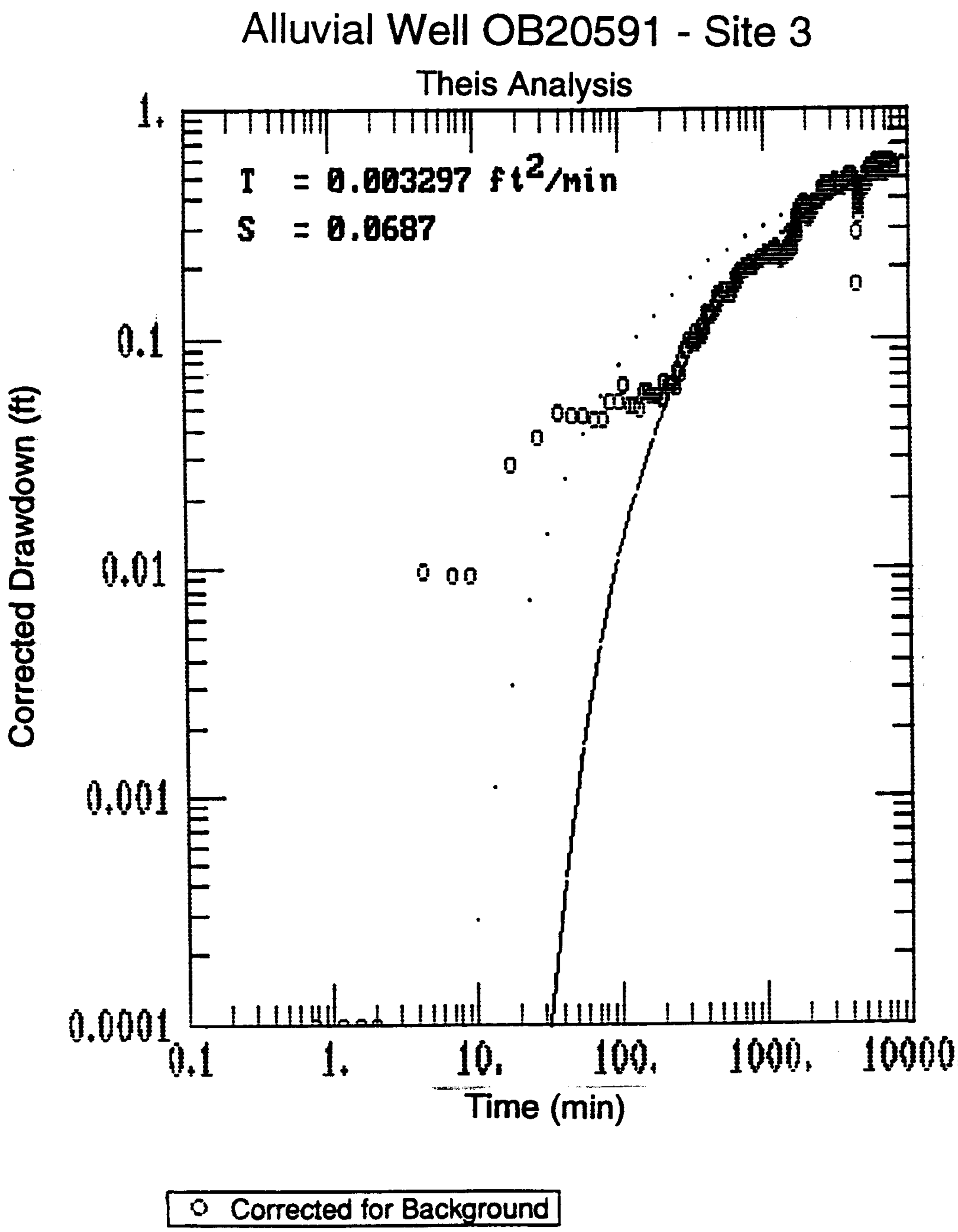
OPERABLE UNIT NO. 2
PHASE II RFI/RI AQUIFER TEST REPORT

OB20591
Cooper-Jacob Analysis

FIGURE 65 NOVEMBER, 1992

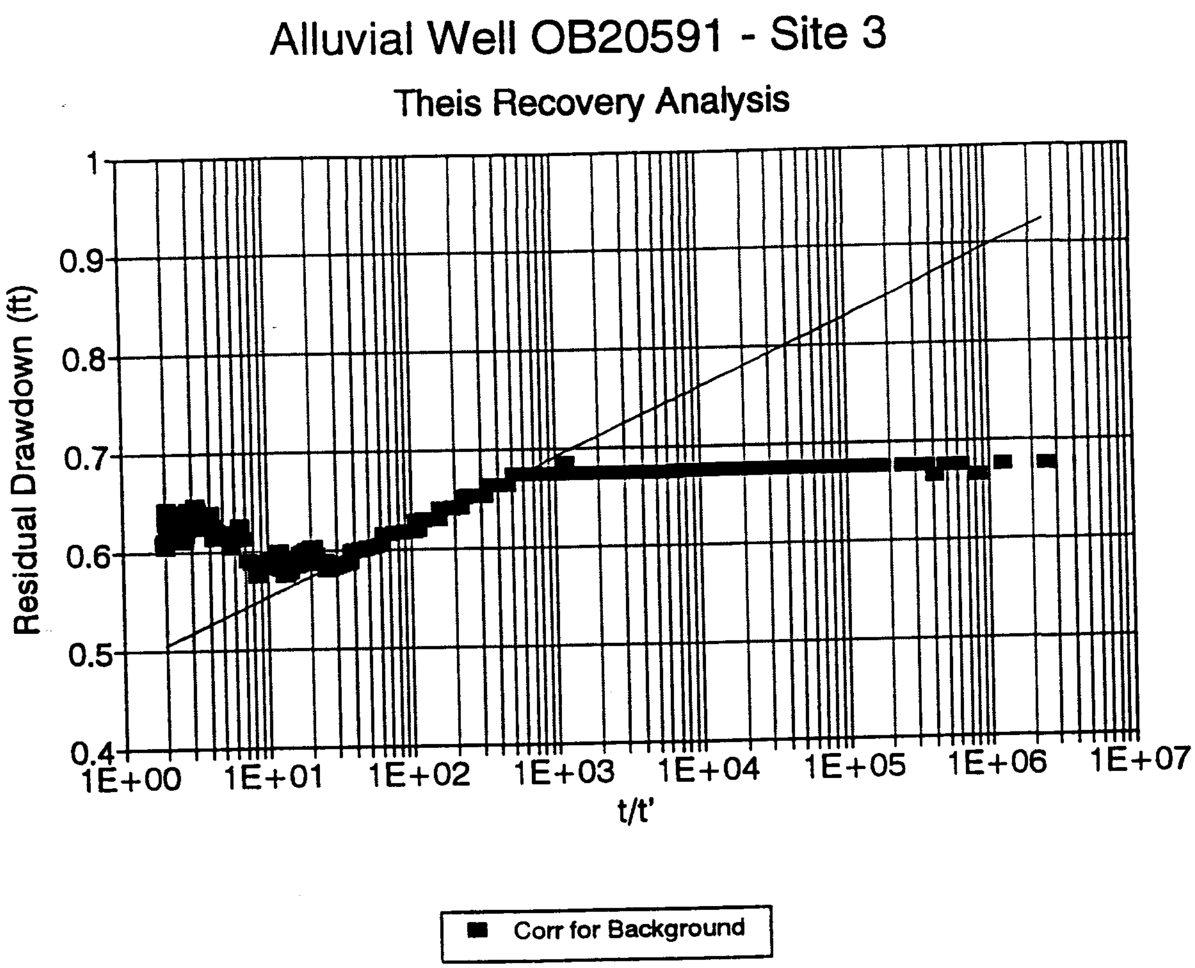


U.S. DEPARTMENT OF ENERGY
Rocky Flats Plant, Golden, Colorado

OPERABLE UNIT NO. 2
PHASE II RFI/RI AQUIFER TEST REPORT

OB20591
Theis Analysis

FIGURE 66 NOVEMBER, 1992



T = .01995 ft^2/min
S = N/A

U.S. DEPARTMENT OF ENERGY
Rocky Flats Plant, Golden, Colorado

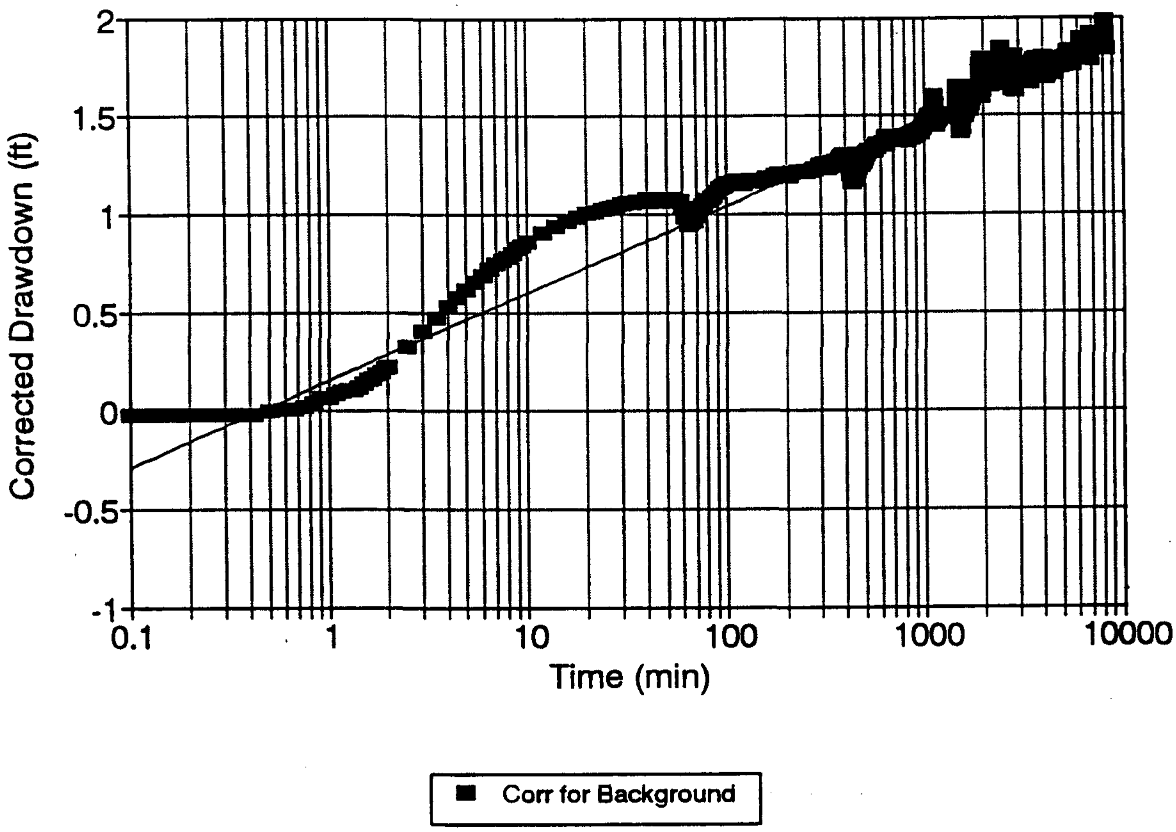
OPERABLE UNIT NO. 2
PHASE II RFI/RI AQUIFER TEST
REPORT

OB20591
Theis Recovery Analysis

FIGURE 67 NOVEMBER, 1992

Alluvial Well PW20691 - Site 3

Cooper - Jacob Analysis



$T = .003090\ ft^2/min$
$S = .01796$

U.S. DEPARTMENT OF ENERGY
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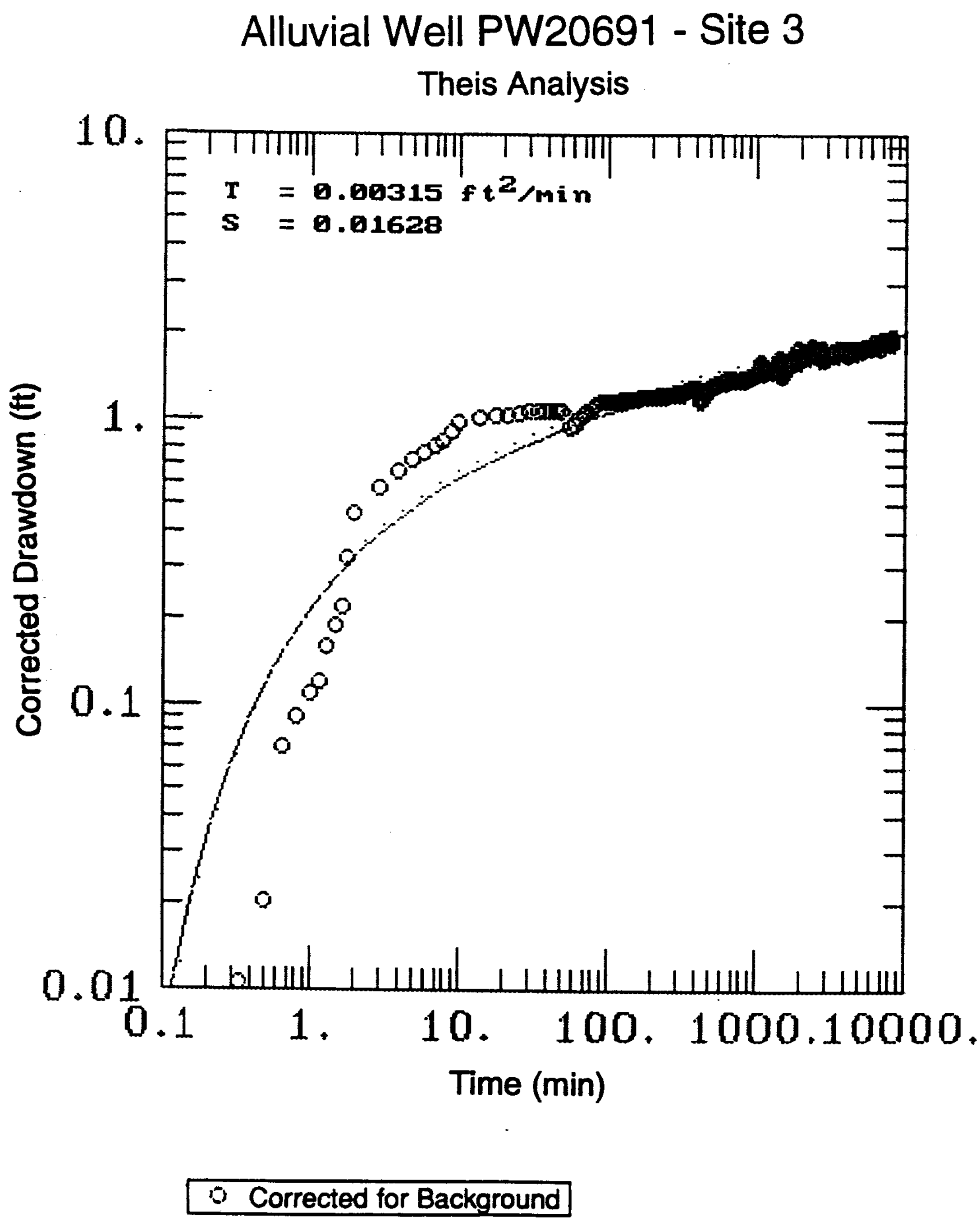
OPERABLE UNIT NO. 2
PHASE II RFI/RI AQUIFER TEST REPORT

PW20691
Cooper-Jacob Analysis

FIGURE 68 NOVEMBER, 1992

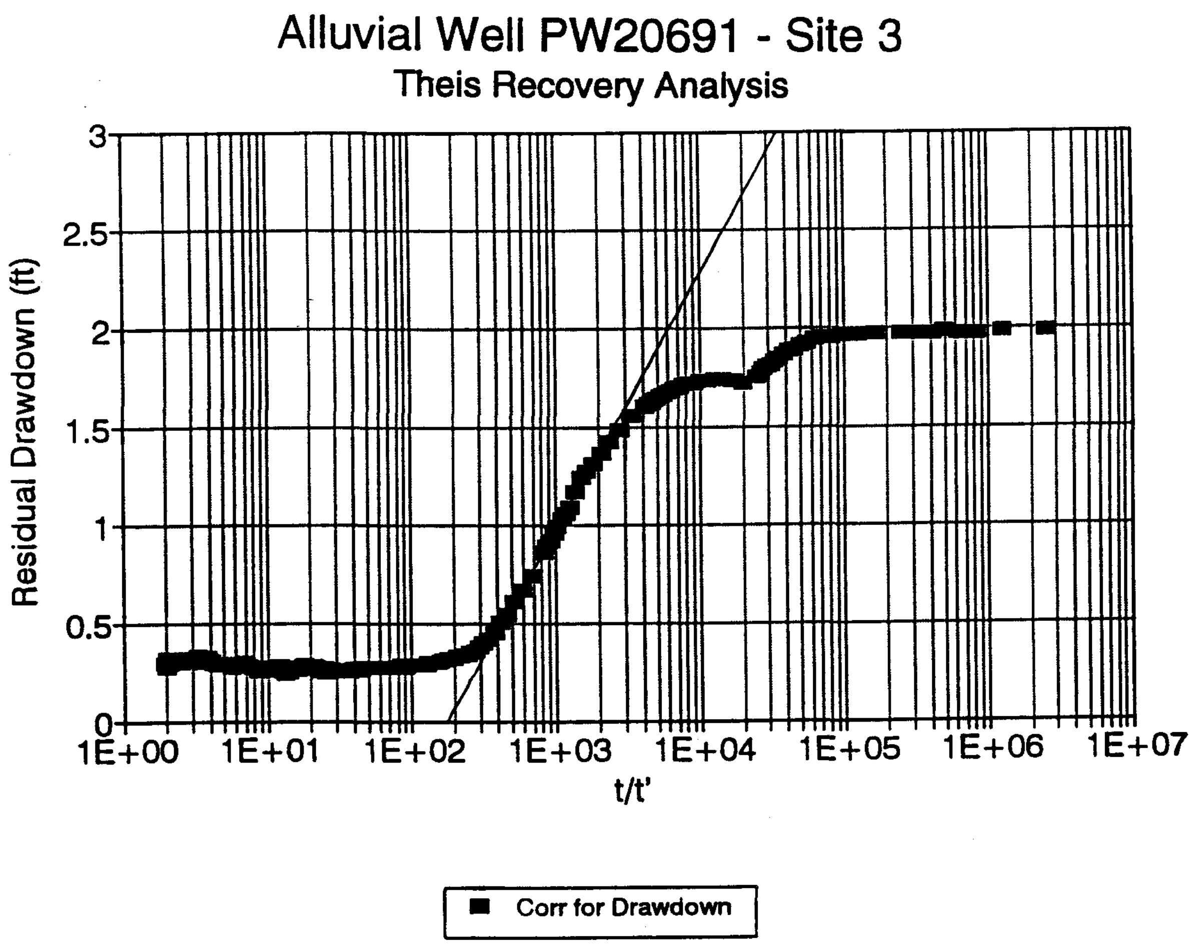


U.S. DEPARTMENT OF ENERGY
Rocky Flats Plant, Golden, Colorado

OPERABLE UNIT NO. 2
PHASE II RFI/RI AQUIFER TEST
REPORT

PW20691
Theis Analysis

FIGURE 69 NOVEMBER, 1992



T = .001052 ft^2/min
S = N/A

U.S. DEPARTMENT OF ENERGY
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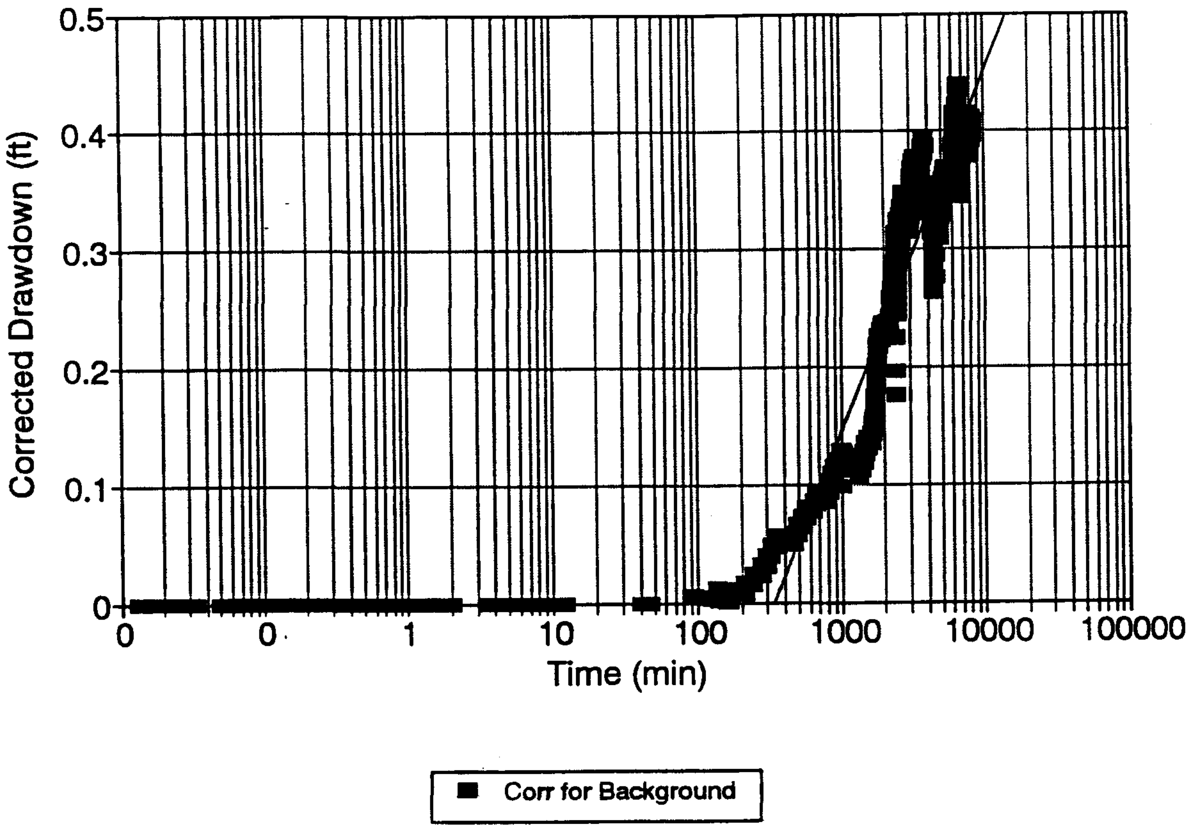
PHASE II RFI/RI AQUIFER TEST
REPORT

PW20691
Theis Recovery Analysis

FIGURE 70 NOVEMBER, 1992

Alluvial Well 1787 - Site 3

Cooper - Jacob Analysis



T = .004480 ft^2/min
S = .03218

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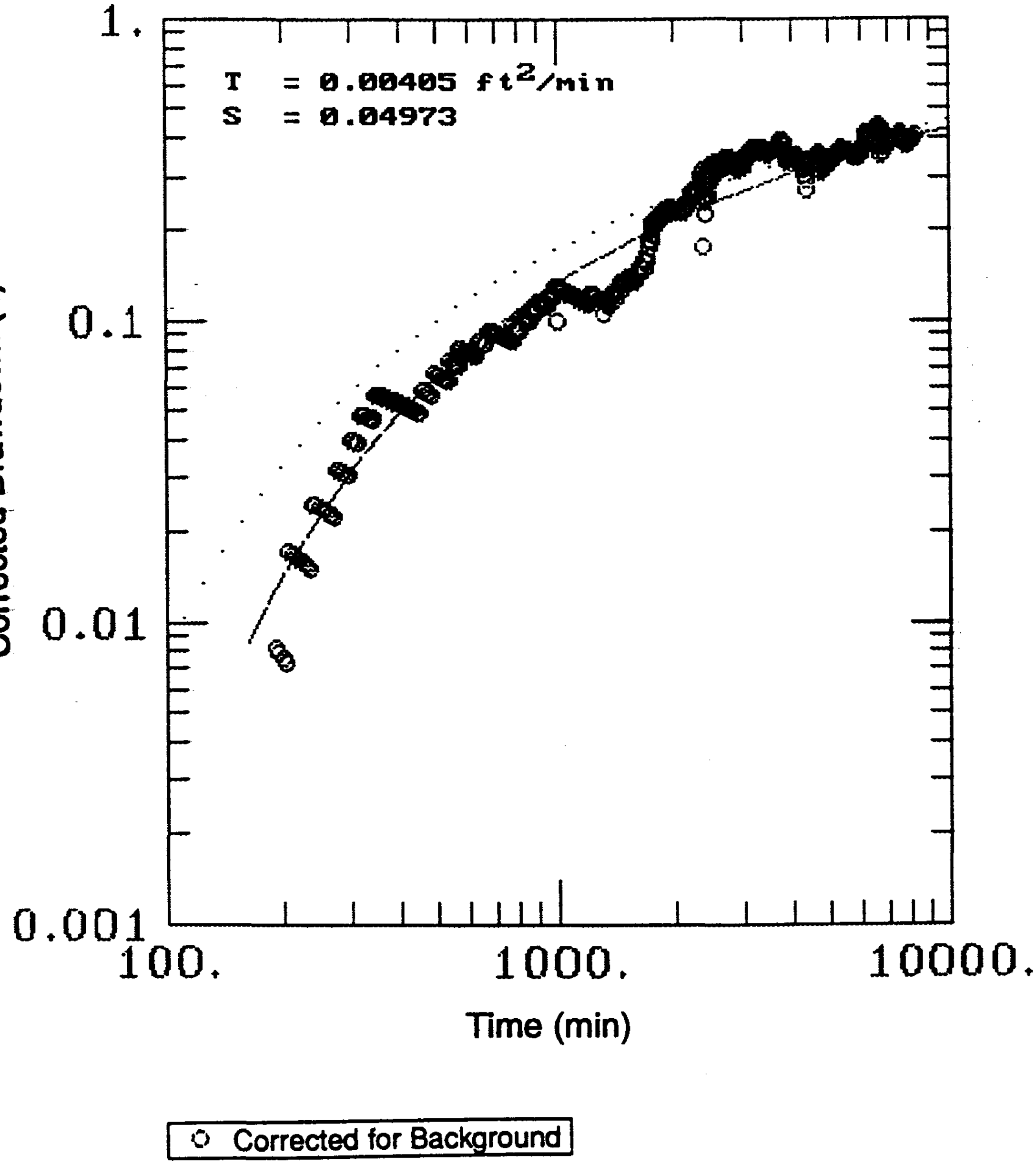
PHASE II RFI/RI AQUIFER TEST
REPORT

1787
Cooper-Jacob Analysis

FIGURE 71 NOVEMBER, 1992

Alluvial Well 1787 - Site 3

Theis Analysis



U.S. DEPARTMENT OF ENERGY
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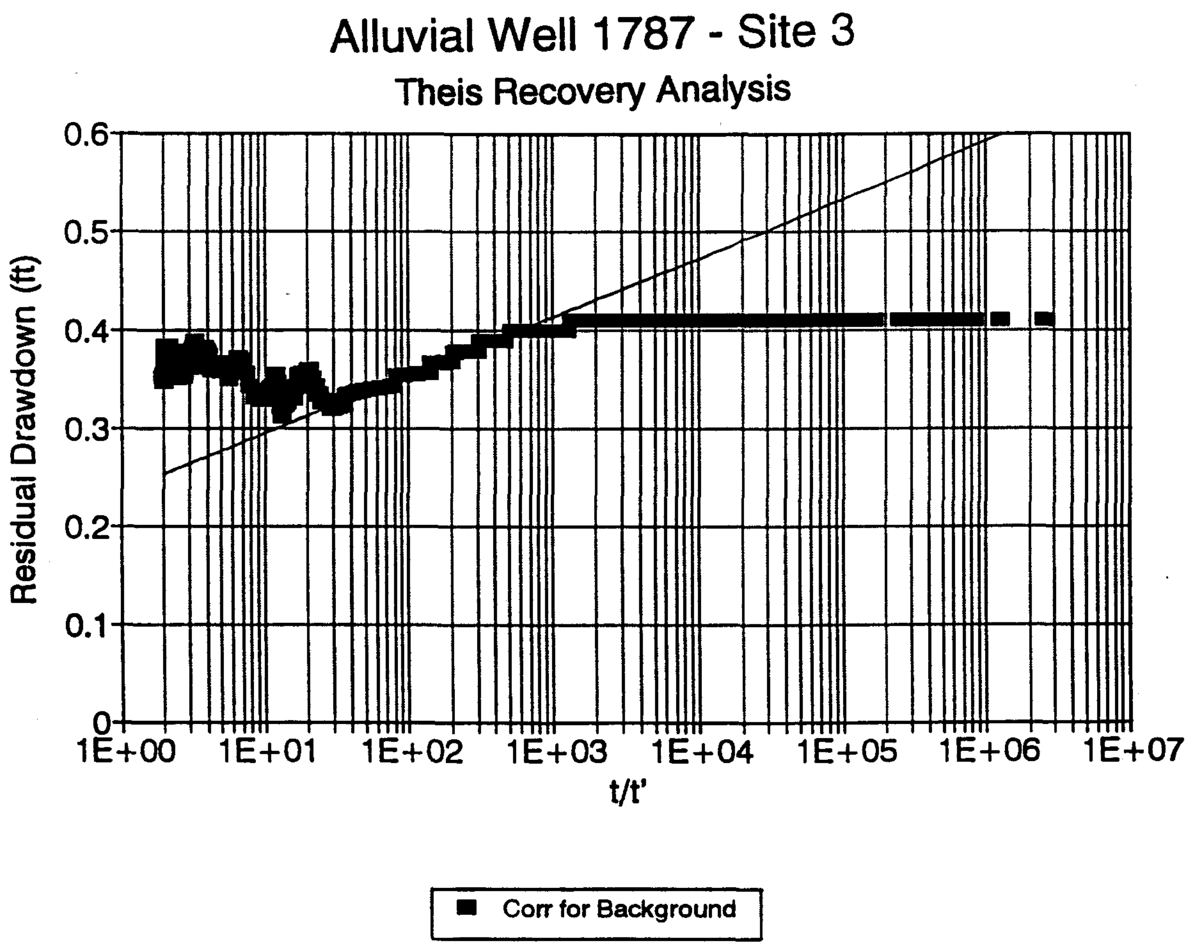
PHASE II RFI/RI AQUIFER TEST
REPORT

1787
Theis Analysis

FIGURE 72 NOVEMBER, 1992



T = .02307 ft^2/min
S = N/A

U.S. DEPARTMENT OF ENERGY
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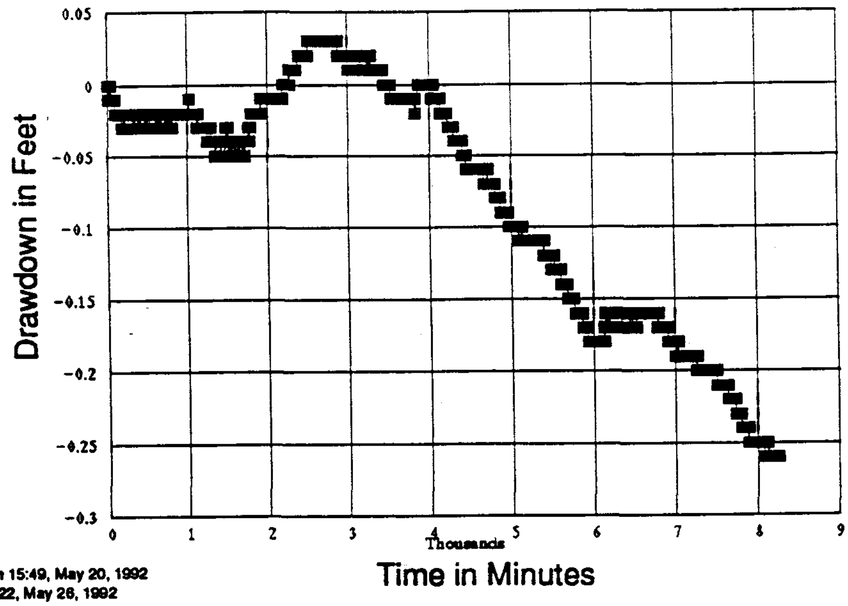
OPERABLE UNIT NO. 2
PHASE II RFI/RI AQUIFER TEST REPORT

1787
Theis Recovery Analysis

FIGURE 73 **NOVEMBER, 1992**

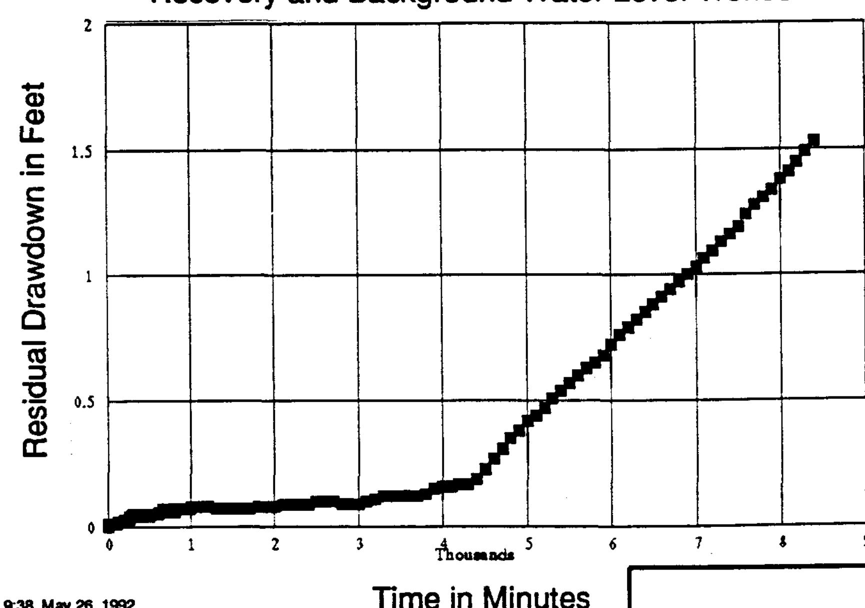
BEDROCK WELL 20791 - SITE 3

Uncorrected Time - Drawdown Curve



From 15:49, May 20, 1992
to 9:22, May 26, 1992

Recovery and Background Water Level Trends



From 9:38, May 26, 1992
to 5:41, June 1, 1992

U.S. DEPARTMENT OF ENERGY
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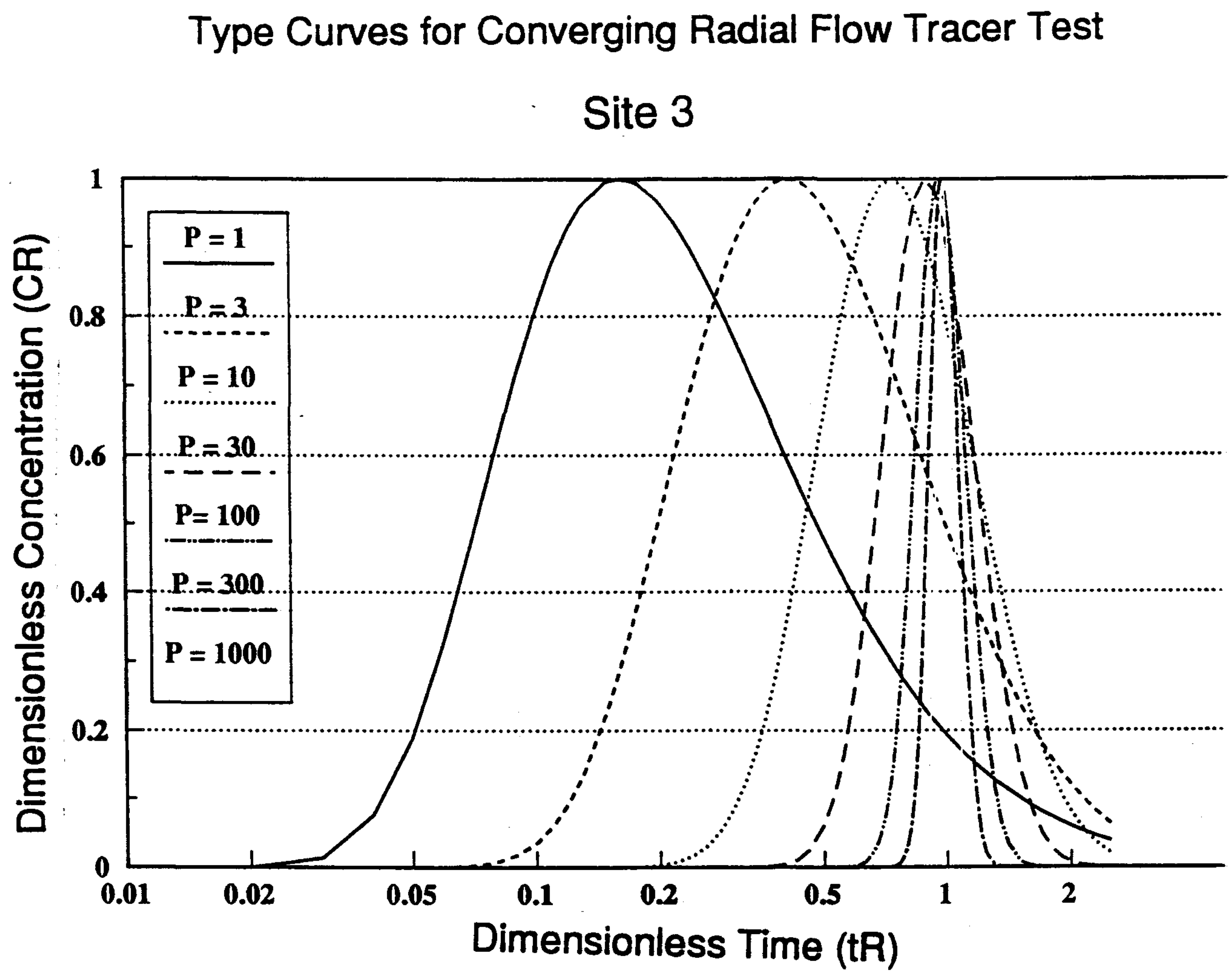
PHASE II RFI/RI AQUIFER TEST
REPORT

Uncorrected Drawdown, Recovery and
Background Water Level Trends
for OB20791

FIGURE 74 NOVEMBER, 1992



U.S. DEPARTMENT OF ENERGY
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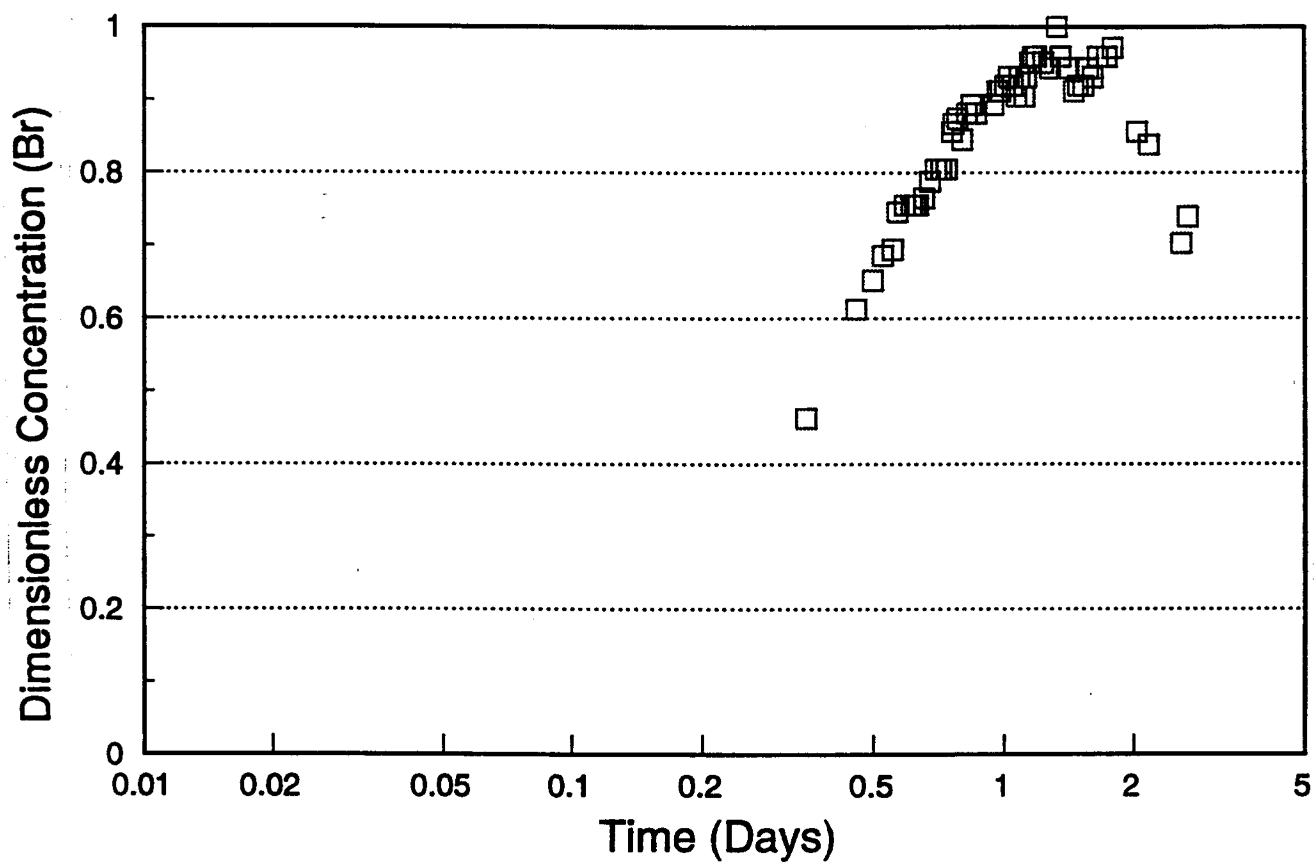
OPERABLE UNIT NO. 2
PHASE II RFI/RI AQUIFER TEST
REPORT

Site 3

Type Curve

FIGURE 75 NOVEMBER,

Tracer Test - Site 3



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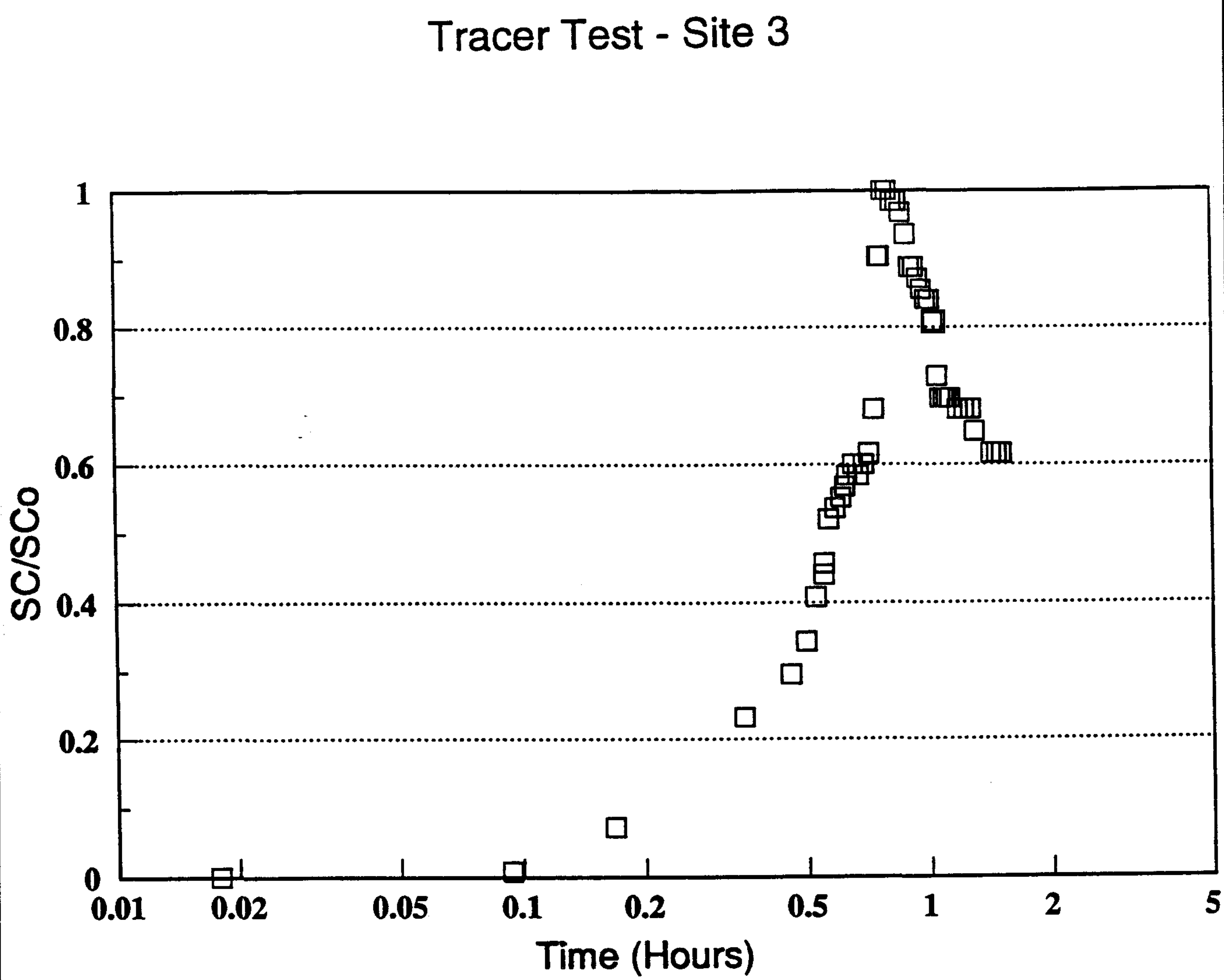
PHASE II RFI/RI AQUIFER TEST
REPORT

Site 3
Lab-Analyzed Bromide Curve

FIGURE 76 NOVEMBER, 1992



U.S. DEPARTMENT OF ENERGY
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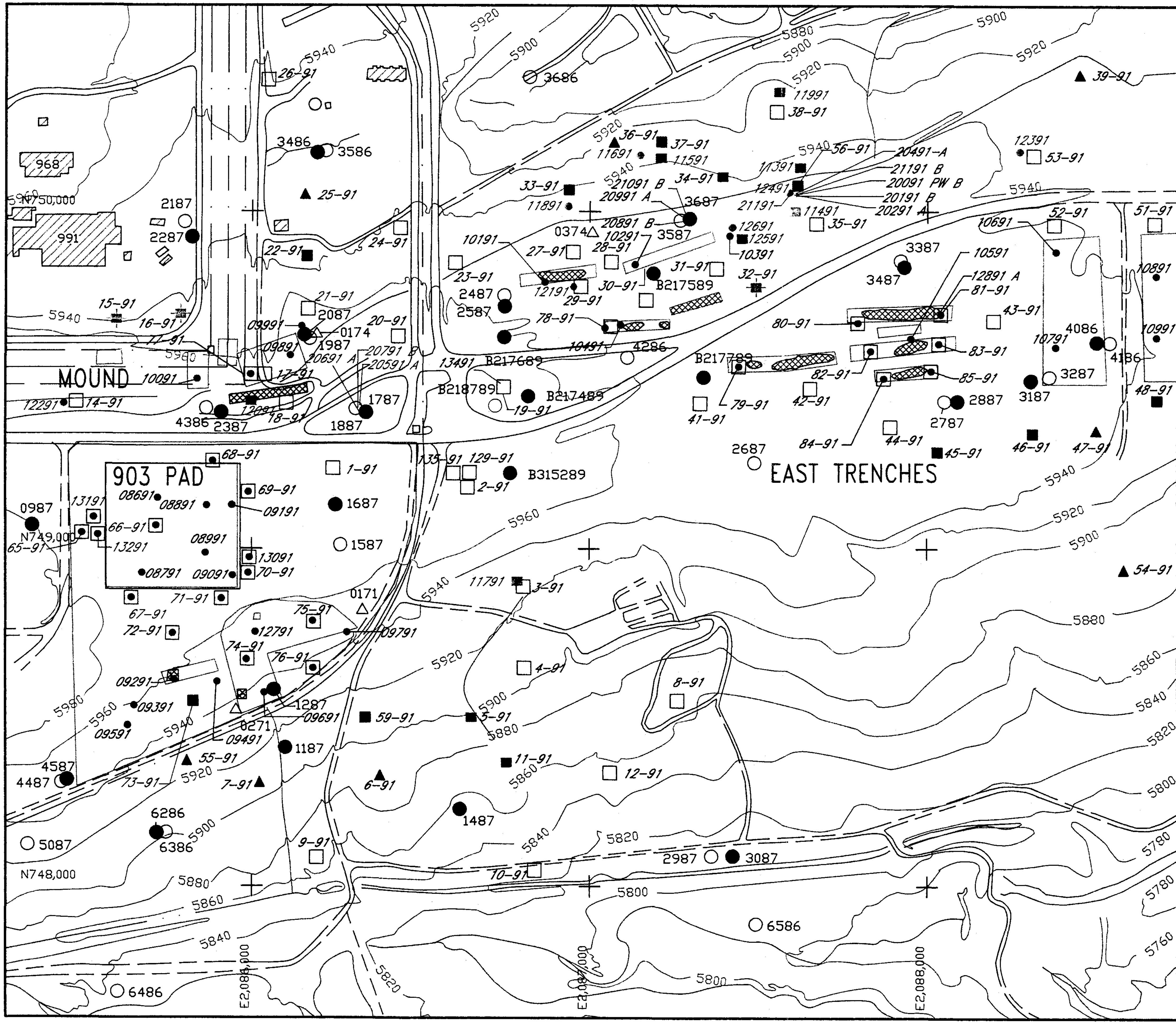
PHASE II RFI/RI AQUIFER TEST
REPORT

Site 3
Field Specific Conductance Curve

FIGURE 77 NOVEMBER, 1992



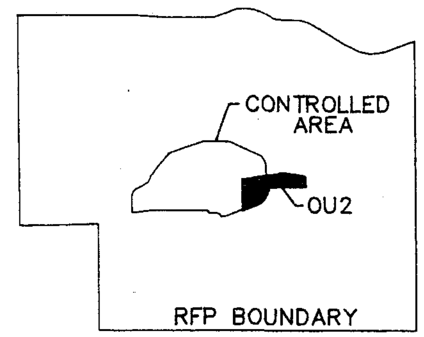
EXPLANATION

- 4587 ● BEDROCK MONITOR WELL
- 4487 ○ ALLUVIAL MONITOR WELL
- 25-91/BH1191 ⊡ PROPOSED SOURCE CHARACTERIZATION ALLUVIAL MONITOR WELL AND BOREHOLE
- 8-91 □ PROPOSED PLUME CHARACTERIZATION ALLUVIAL MONITOR WELL
- 09991 • PROPOSED SOURCE CHARACTERIZATION BOREHOLE
- 60-91 ■ DRIVER WELL SITE – PROPOSED PLUME CHARACTERIZATION ALLUVIAL MONITOR WELL SITE
- 68-91 ▲ CONTINGENCY WELL SITE – PROPOSED PLUME CHARACTERIZATION ALLUVIAL MONITOR WELL SITE
- INDIVIDUAL HAZARDOUS SUBSTANCE SITE LOCATION
- LOCATION OF BARRELS DETERMINED BY VISUAL INSPECTION OR MAGNETOMETER SURVEY
- 11291 ALLUVIAL OFFSET WELL
- 12391 BEDROCK OFFSET WELL
- 11991 ABANDONED LOCATION
- 15-91 NOT DRILLED DUE TO PA OR UNDERGROUND POWERLINES

N

0 150 300

SCALE: 1" = 300'



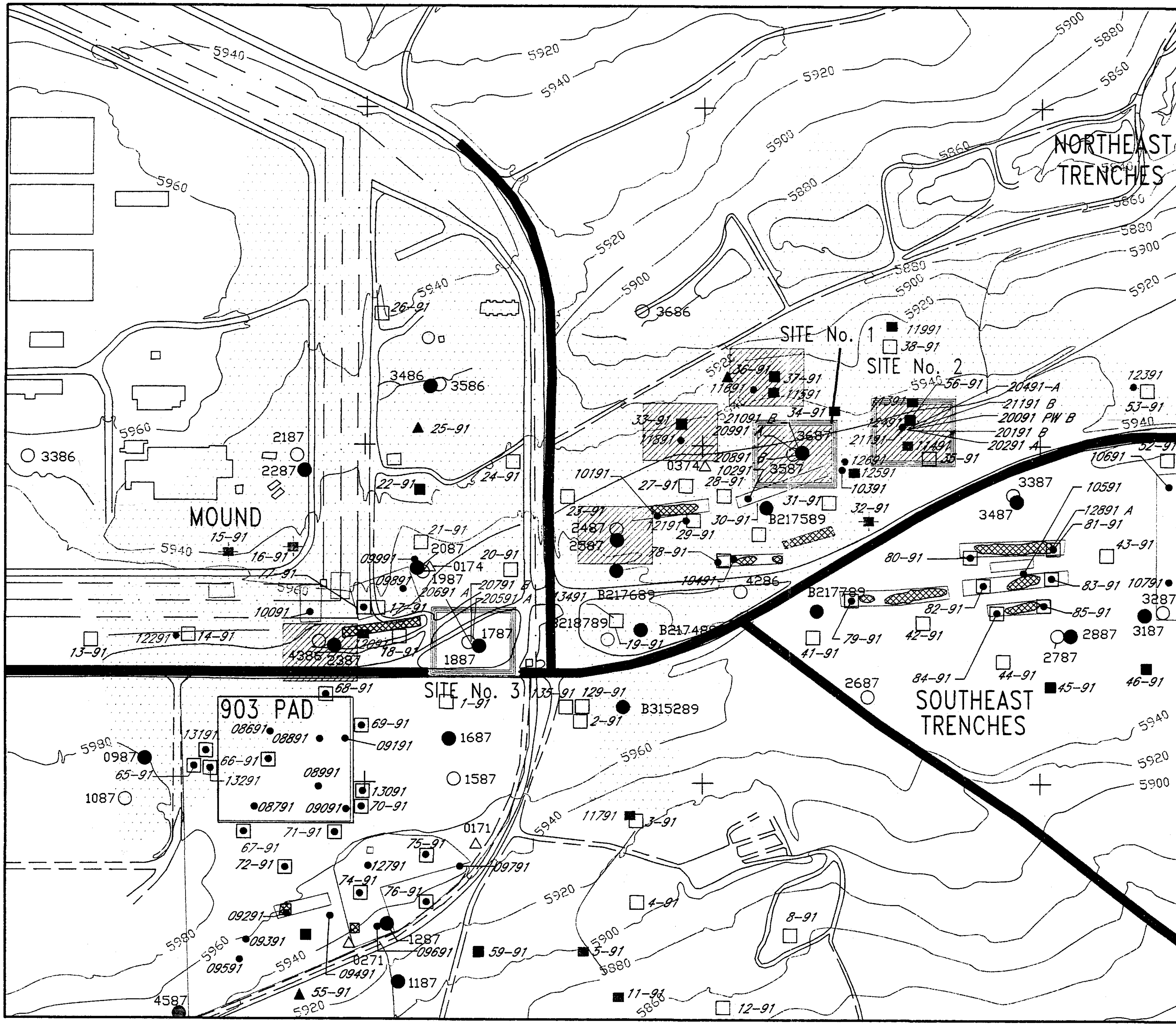
U.S. DEPARTMENT OF ENERGY
Rocky Flats Plant, Golden, Colorado

OPERABLE UNIT NO. 2
PHASE II RFI/RI AQUIFER
TEST REPORT

SITE MAP

FIGURE 1

NOV. 1992



EXPLANATION

- 4587 ● BEDROCK MONITOR WELL
- 4487 ○ ALLUVIAL MONITOR WELL
- 25-91/BH1191 PROPOSED SOURCE CHARACTERIZATION ALLUVIAL MONITOR WELL AND BOREHOLE
- 8-91 □ PROPOSED PLUME CHARACTERIZATION ALLUVIAL MONITOR WELL
- 09991 • PROPOSED SOURCE CHARACTERIZATION BOREHOLE
- 60-91 DRIVER WELL SITE – PROPOSED PLUME CHARACTERIZATION ALLUVIAL MONITOR WELL SITE
- ▲ 68-91 CONTINGENCY WELL SITE – PROPOSED PLUME CHARACTERIZATION ALLUVIAL MONITOR WELL SITE
- INDIVIDUAL HAZARDOUS SUBSTANCE SITE LOCATION
- LOCATION OF BARRELS DETERMINED BY VISUAL INSPECTION OR MAGNETOMETER SURVEY
- 11291 ALLUVIAL OFFSET WELL
- 12391 BEDROCK OFFSET WELL
- 11991 ABANDONED LOCATION
- 15-91 NOT DRILLED DUE TO PA OR UNDERGROUND POWERLINES
- APPROXIMATE AREA OF FLUVIAL DEPOSITION
- LOCATION OF TRANSDUCER PAIRS
- TEST SITE

N

0 150 300

SCALE: 1" = 300'

CONTROLLED AREA

OU2

RFP BOUNDARY

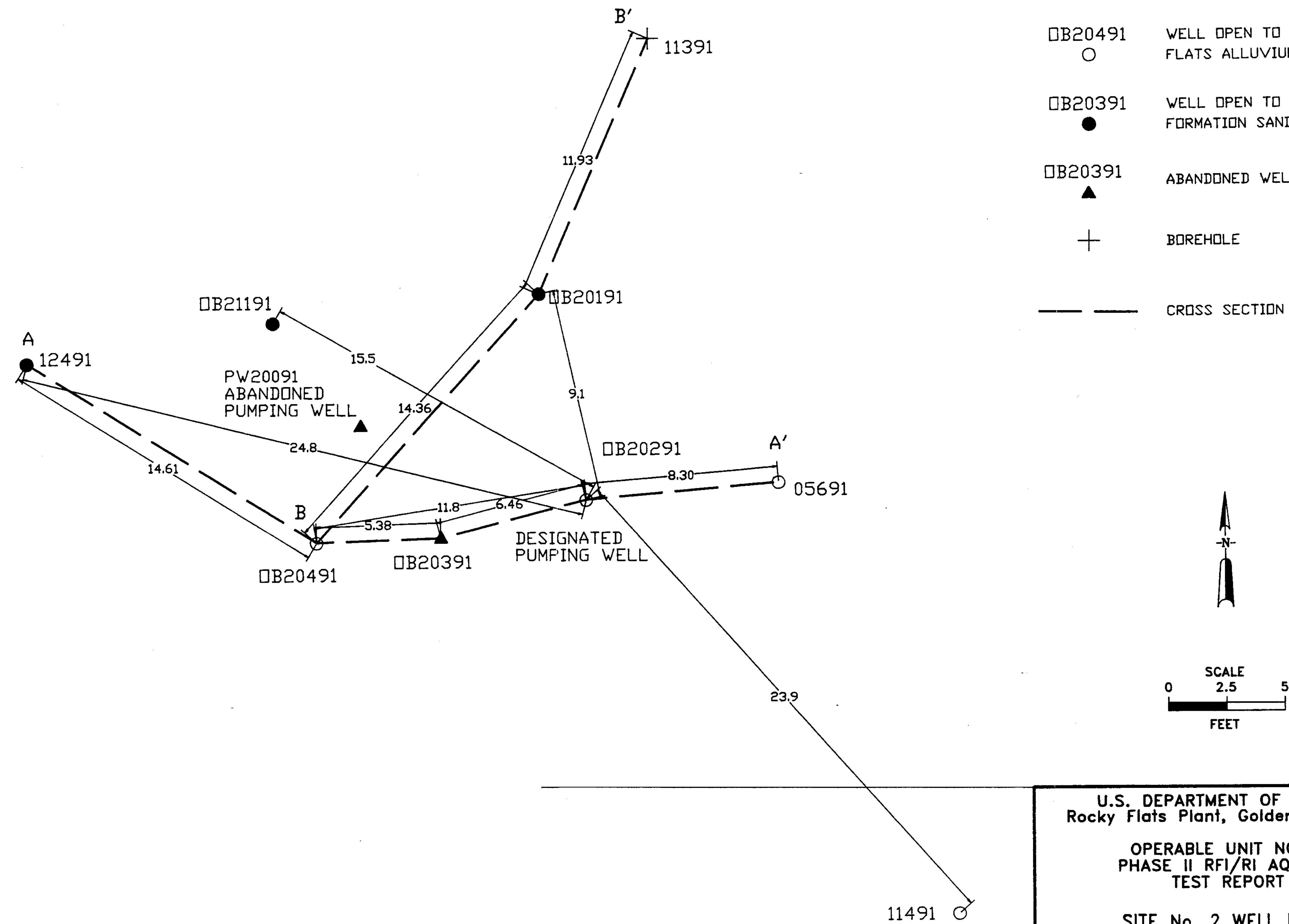
U.S. DEPARTMENT OF ENERGY
Rocky Flats Plant, Golden, Colorado

OPERABLE UNIT NO. 2
PHASE II RFI/RI AQUIFER
TEST REPORT

TEST SITE LOCATION MAP

FIGURE 2

NOV. 1992



U.S. DEPARTMENT OF ENERGY
Rocky Flats Plant, Golden, Colorado

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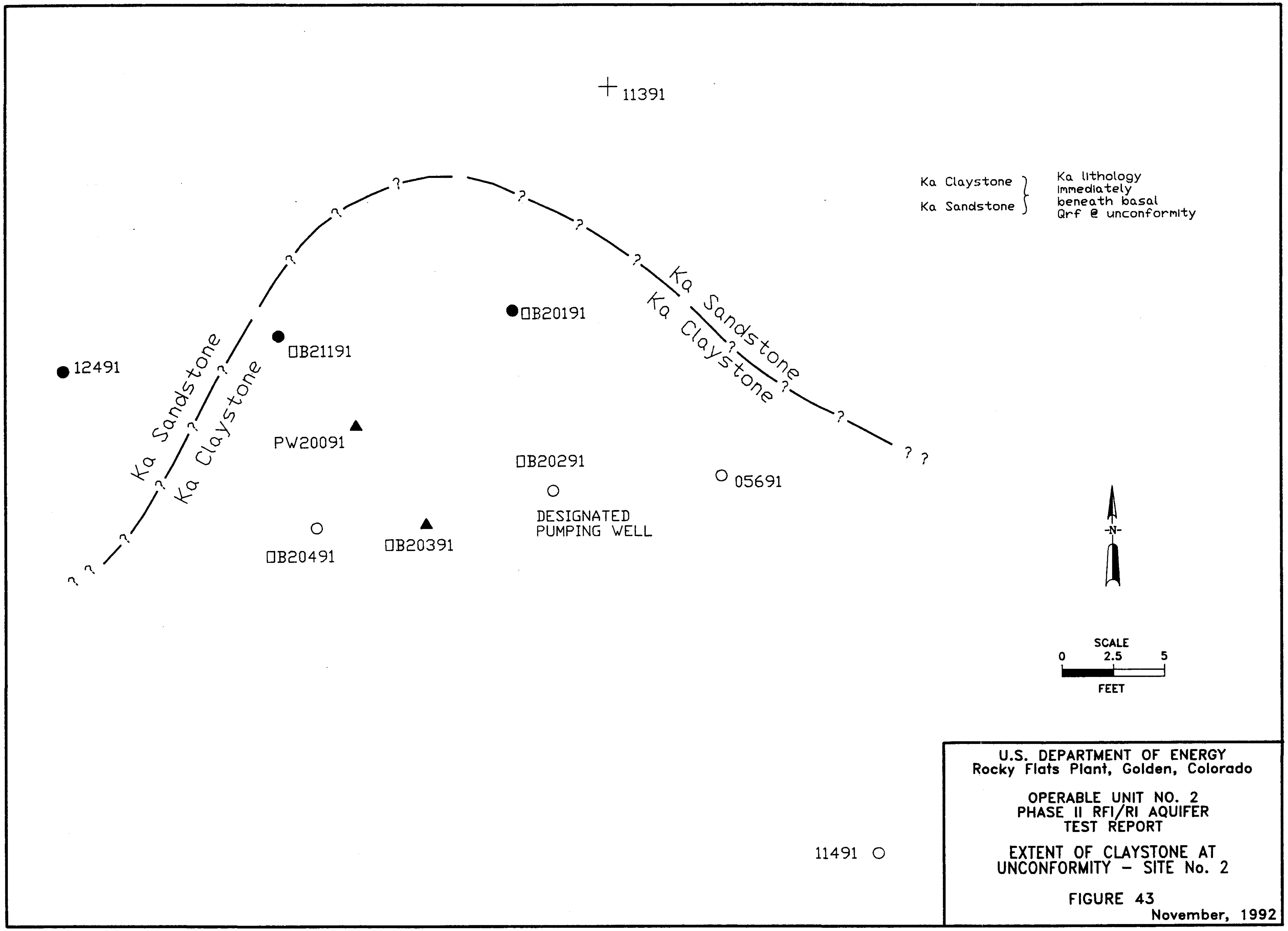
PHASE II RFI/RI AQUIFER
TEST REPORT

SITE No. 2 WELL FIELD

FIGURE 42
November, 1992



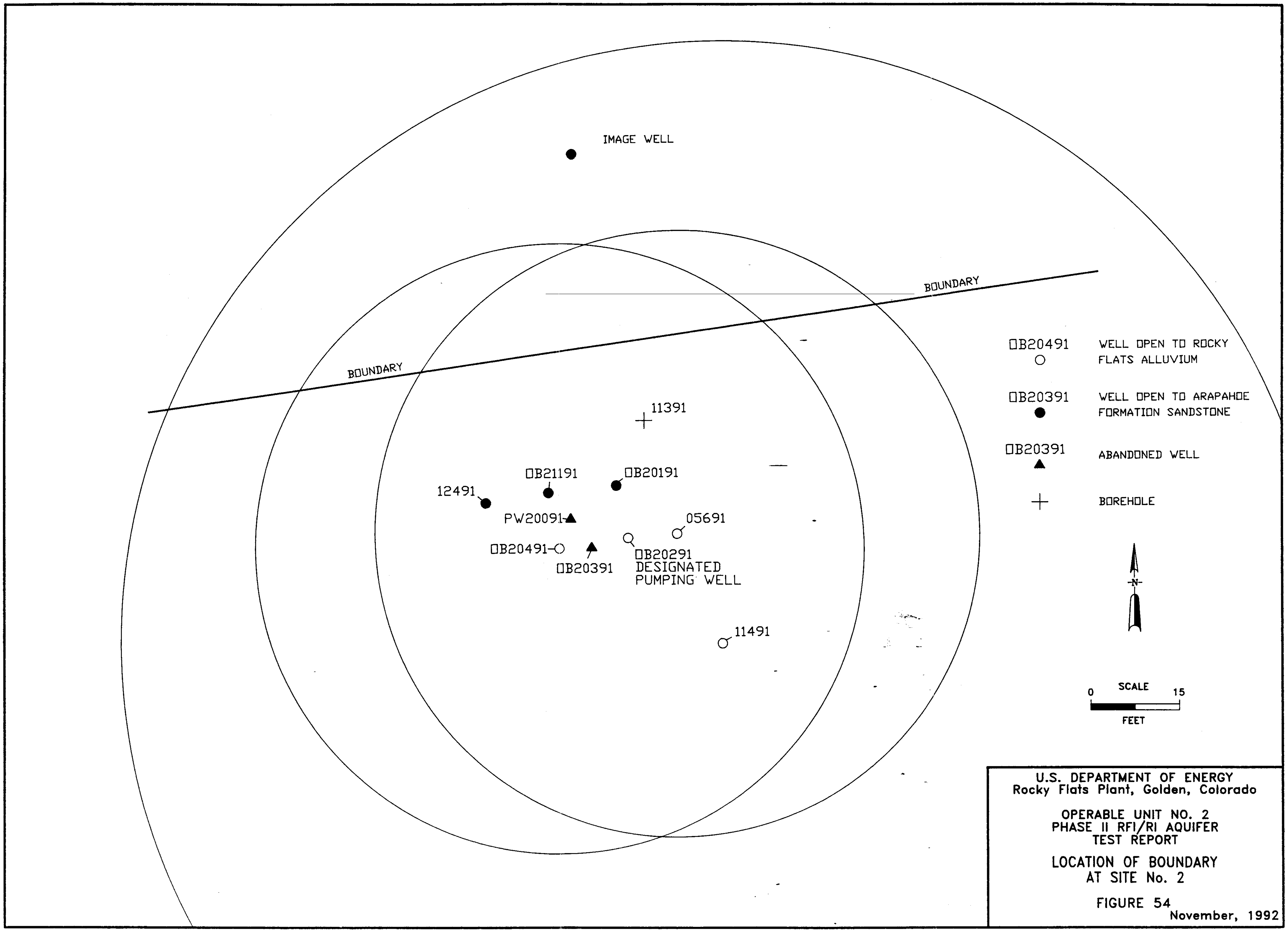
U.S. DEPARTMENT OF ENERGY
Rocky Flats Plant, Golden, Colorado

OPERABLE UNIT NO. 2
PHASE II RFI/RI AQUIFER
TEST REPORT

EXTENT OF CLAYSTONE AT
UNCONFORMITY – SITE No. 2

FIGURE 43

November, 1992



U.S. DEPARTMENT OF ENERGY
Rocky Flats Plant, Golden, Colorado

OPERABLE UNIT NO. 2
PHASE II RFI/RI AQUIFER
TEST REPORT

LOCATION OF BOUNDARY
AT SITE No. 2

FIGURE 54
November, 1992